FINAL REPORT

Demonstration of Metastable Intermolecular Composites (MIC) on Small Caliber Cartridges and CAD/PAD Percussion Primers

ESTCP Project WP-200205

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14. ABSTRACT
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Abbreviations and Acronyms

ATF	Armaments Technology Facility
ARDEC	Armament Research, Development & Engineering Center
BET	Brunauer-Emmett-Teller
BHA	Black Hills Ammunition, Inc.
CAD	cartridge actuated device
CCB	Configuration Control Board
CHPPM	Center for Health Promotion and Preventative Medicine (US Army)
DEMIL	demilitarization
DFT	Design Feasibility Testing
DOD	Department of Defense
DSC	Differential Scanning Calorimetry
DVT	Design Verification Testing
ECP	Engineering Change Proposal
EI	Engineering Investigations
EMT	Energetic Materials Technology
EPA	Environmental Protection Agency
EPVAT	Electronic Pressure, Velocity And Action Time
FA	Frankford Arsenal
FLIR	forward looking infrared
GFM	government furnished material
IMP	Innovative Materials and Processes, LLC
LANL	Los Alamos National Laboratory
LAT	Lot Acceptance Test
LCAAP	Lake City Army Ammunition Plant
MANTECH	DOD Manufacturing Technology Program
MIC	metastable intermolecular composites
MIC-JWG	MIC Joint Working Group
NAS	Naval Air Station
NAVAIR	Naval Air Systems Command
NSWC/IHDIV	Naval Surface Warfare Center/Indian Head Division
OSHA	Occupational Safety Health Administration

PAD	propellant actuated device
PETN	pentaerythritol tetranitrate
PM-MAS	Project Manager for Maneuver Ammunition Systems
ppm	parts per million
QC	quality control
QE	quality evaluations
SATTP	Strauss Avenue Thermal Treatment Point
SD	standard deviation
SERDP	Strategic Environmental Research and Development Program
SOP	standard operating procedure
SWR	solid waste recycler
TEM	transverse electron microscopy
TGA	thermal gravimetric analysis
TNR	trinitroresorcinol
TNT	2,4,6-trinitrotoluene
UFAL	ultra-fine aluminum

Acknowledgements:
This program was a joint US Army and US Navy effort to eliminate lead-based primer compositions from small arms and CAD/PAD percussion primers. Funding for this effort was shared by ESTCP and the US Navy CAD/PAD Joint Program Office. A number of people at ARDEC and NSWC/IHDIV, including both on-site and off-site contractors, were directly responsible for successful completion of this program. At ARDEC, Tom Doris and Chris Csernica provided valuable skill and expertise in developing and testing MIC primer formulations, and generously allowed Navy researchers access to their facilities when needed. Additionally, Dr. Rao Yalamanchilli of ARDEC coordinated the ATF firings there, and was instrumental in producing the primers and loading the cartridges needed for the supplemental testing at BHA.

At NSWC/IHDIV Todd Allen was responsible for the formidable tasks of assembling all primer and cartridge hardware needed for CAD testing, coordinating NSWC and IMP loading operations, and arranging for the tests at NSWC/IHDIV. Dr. Peter Ostrowski of EMT archived and analyzed the data obtained in those tests.

Finally, Dr. Jan Puszynski and Dr. Jacek Swiatkiewicz of IMP are recognized for their efforts in developing the basic Al/Bi_2O_3 MIC formulation used in this test program and the water-based mixing and loading technique eventually adopted at both ARDEC and NSWC. They also conducted sensitivity tests of finished MIC primers, loaded the primers into all cartridges tested at NSWC/IHDIV, and directed the ballistic tests at BHA.

Abstract:
This report documents demonstration testing of MIC primer compositions designed to eliminate lead from the primers used in small arms ammunition and cartridge actuated devices. This effort has shown that an Al/Bi_2O_3 composition can be successfully mixed and wet-loaded into existing US Army and US Navy primer hardware. Subsequent testing in M855 5.56 mm ammunition as well as a variety of Navy impulse and delay cartridges has shown that the primer provides performance essentially equivalent to the lead-based compositions presently in use. Thus, the new primer composition meets the objective for a drop-in replacement for the lead compounds. While the test results are positive and the MIC primer meets all performance specifications, additional work is needed to refine the primer composition to achieve faster action time in small arms cartridges and to eliminate occasional misfires.

1. Introduction

1.1 Background

Current percussion primers in small caliber ammunition (i.e. 5.56mm, 7.62mmm cal .50 and 20mm) use a lead styphnate based primer formulation that poses a long term hazard to the environment and the operator of the weapon since airborne vaporized lead results from each successfully fired cartridge. Lead styphnate based primer compositions are currently specified in all of the US Army's combat small caliber ammunition and in many cartridge activated devices and propellant actuated devices (CAD/PAD) used in US Navy aircraft ejection systems, countermeasure applications, and stores release systems. The CAD/PAD devices are used by all DOD components and foreign military that utilize US manufactured aircraft. Lead is a known toxic material, which pollutes test ranges and exposes the manufacturers and users of these devices to serious health hazards liabilities. Lead is regulated by the Environmental Protection Agency (EPA) and the Occupational Safety Health Administration (OSHA). Current EPA and OSHA regulations are directly impacting range and testing operations. Stricter regulations in the future will seriously impact or force closing of production, testing and range operations. With the current production rate for all small caliber ammunition (less than 20 mm), the quantity of lead to be consumed for percussion primer production alone is well over 23,686 pounds or nearly 12 tons annually.

Small caliber percussion primers generally consist of a brass cup loaded with the charge composition and a brass anvil pressed into the charge. Figure 1 shows the US Army No. 41 primer prior to inserting the anvil. When the cup is struck by a firing pin, the friction and impact sensitive charge is crushed between the bottom of the cup and anvil, causing ignition. The hot ignition products flow out of the cup around the legs of the anvil to ignite the next element in the ignition train of the weapon system. For the Army No. 41 primer, this would be the ball powder main charge in small caliber ammunition. For the Navy PVU-1/A primer, this would be either a transition charge or an output charge, depending on the particular application.

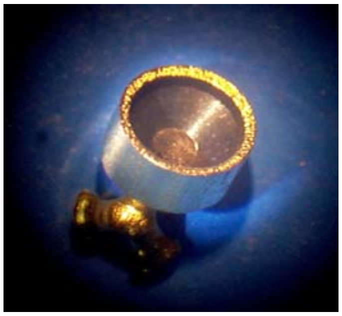


Figure 1 – No. 41 Small Caliber Percussion Primer Showing Loaded Cup and Tripod Anvil

While the No. 41 and PVU-1/A primers are similar in size, there are some important differences. The No. 41 primer is designed to provide sufficient pressure to quickly ignite the double base ball powder main charge, and thus utilizes a tripod anvil and the FA-956 primer composition, which contains PETN and aluminum powder for added brisance (Table 1(a)). The PVU-1/A is designed for "soft" ignition of delay cartridges, and uses a bipod anvil and the 5086 primer composition (Table 1(b)), which provides a lower output pressure than FA-956. Figure 2 is a photograph of a loaded PVU-1/A, illustrating the small size.

Ingredient	Weight %
Normal Lead Styphnate	37.0
Tetracene	4.0
Barium Nitrate	32.0
Antimony Sulfide	15.0
Aluminum Powder	7.0
PETN	5.0

(a) FA-956 Primer Mix (No. 41 Primer)

Ingredient	Weight %
Normal Lead Styphnate	26.0
Barium Nitrate	41.5
Tetracene	2.0
Calcium Silicide (Treated)	10.5
Antimony Sulfide	20.0

(b) 5086 Primer Mix (PVU-1/A Primer)

Table 1. Primer Mix Compositions for No. 41 and PVU-1/A Primers

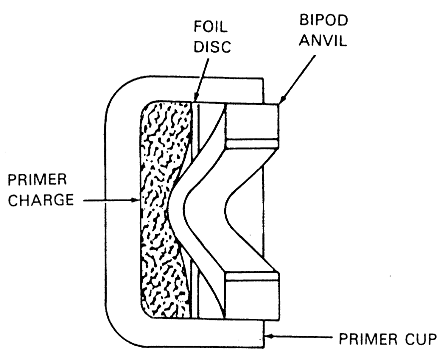


Figure 2 – PVU-1/A Percussion Primer

1.2 Objectives of the Demonstration

This test program was designed to demonstrate that a lead free primer composition based on nano-sized particles of Metastable Intermolecular Composites (MIC) can be used as an alternative to the lead styphnate formulations and comply with all military specifications for reliability, operation in extreme temperature environments, and storage life. As is summarized in Table 2, the advantage of using MIC materials in primers is the elimination of lead, a known toxic component, but also elimination of other heavy metal compounds also found in the primer compositions. The use of the MIC composition should be invisible to the user since by design, the performance will be equivalent to the current primer. Thus, the demonstration of MIC technology presents an opportunity for replacing the conventional primer composition for small caliber ammunition and its derivative applications with an alternative composition that is nontoxic and environmentally benign.

Target HazMat	Current Process	Application	Current Specification	Affected Programs	Candidate Parts/Substrate
Lead Styphnate, Barium Nitrate, & Antimony Sulfide	FA 956 (Army) Mix 5086 (Navy)	Percussion Primers	MIL-P-46610E WS 21535B	Small Caliber Ammunition / CAD-PAD Cartridges	Lead-free Primer Composition, Metastable Intermolecular Composites

Table 2. Target HazMat Summary

The purpose of this demonstration was to evaluate the performance of MIC primers with compositions formulated from commercially available lead-free nano-scale powders. For these tests, the MIC composition has been substituted for the lead-based primer composition currently used in conventional small caliber percussion primers. Small caliber percussion primers are used by the Army in small caliber ammunition and by the Navy in several CAD/PAD applications. The test plan [1] outlines the test protocols for the Army small caliber No. 41 primer (dwg # 10534279) and the Navy PVU-1/A primer (MIL-P-46610E Primers, Percussion) with the following performance elements to be demonstrated;

- primer sensitivity
- ignitability
- action time
- interior ballistics

Primer sensitivity testing was conducted in both Army (No. 41) and Navy (PVU-1/A) ball drop test fixtures as per the specification for each primer. These were the only tests that defined the performance of each individual primer lot. All other testing was application-oriented, and as such, determined the ability of each primer to function properly in each application, but did not directly measure the performance of the primer. The Army application testing took place in a controlled firing range environment and encompassed some of the specifications from the Small Caliber Ammunition Test Procedures for the 5.56mm cartridges (SCATP-5.56,) by assembling complete M855 cartridges with MIC primers. A listing of the documents containing detailed test procedures for the cartridges used in this program is supplied in Section 7.3 below. Requests for copies of SCATP-5.56 may be addressed to:

Commander
U.S. Army Armament Research,Development and Engineering Center
ATTN; AMSTA-AR-QAC-C
Picatinny Arsenal, NJ 07806-5000

Copies of the Navy SOPs cannot be taken outside of the CAD/PAD test facilities at NSWC/IHDIV, and are therefore unavailable to all but Navy employees and official visitors. The purpose of the listing is to document the SOPs used should any questions arise concerning which tests were actually conducted. Qualified personnel who desire to read these documents must arrange an official visit to the CAD Engineering Department. Visit Requests may be sent to:

Michael Adams
Head, CAD/PAD Department
4393 Benson Road, Suite 120
Indian Head, MD 20640

For the CAD/PAD applications, five cartridges were selected for the demonstration plan. The selected cartridges include worst-case conditions as far as igniting the cartridge main charge, and they also represent the major class of cartridges that employ PVU-1/A percussion primers. The selected cartridges were assembled, test fired and evaluated in accordance with their respective drawings, product specifications, LAT procedures, and SOPs. The rationale for selecting the cartridges that were tested is discussed in Section 1.4 below. The corresponding military specifications, test procedures, and SOPs are referenced in Sections 7.2 and 7.3. A joint test protocol was not required for this program.

All testing of the No. 41 percussion primers took place in ARDEC test facilities located at Picatinny Arsenal, NJ. Application testing in 5.56mm ammunition was conducted there in the ATF 100 meter range.

Sensitivity testing of PVU-1/A percussion primers was conducted in NSWC/IHDIV test facilities in Indian Head, MD and also at Innovative Materials and Processes, LLC, in Rapid City, SD, where the primers were manufactured. All PVU-1/A application testing was conducted in CAD/TEST facilities at NSWC/IHDIV.

1.3 Regulatory Drivers

The following regulations and directives are applicable to this program:

Executive Order 12856, Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements 1994

NEPA – National Environmental Policy Act, 1969

OPNAVINST 4110.2, Hazardous Material Control and Management

Army 3.3b Reduce hazardous Components in Ordnance and Alternative Treatment for Hazardous Waste from Ordnance Processing

Navy 3.1.6.C, Energetic Production Pollution Prevention

Air Force 974, Reduction of Lead Exposure at Firing Ranges

Zero Discharge Study for Lake City Army Ammunition Plant, Aug 1997

1.4 Stakeholder/End-User Issues

The successful demonstration of the Army MIC primer will be used by the Program Manager for Maneuver Armament Systems (PM-MAS) to proceed with the authorization for an ammunition-based qualification test program that will lead to an Engineering Change Proposal (ECP) for qualifying the MIC primers. Once approval has been granted, an Army manufacturing technology (MANTECH) program sponsored by the PM-MAS would be required to proceed with the equipment prototyping and process alteration required to adopt the new MIC primer at Lake City Army Ammunition Plant (LCAAP). The ECP process would be coordinated at the Army Joint Munitions Command (Rock Island Arsenal) level with the item manager for the small caliber ammunition assembling the package for presentation to a level 1 Configuration Control Board (CCB). This CCB is a multi service panel board with representative from all Department of Defense (DOD) services since the primer would be used by all DOD organizations. After the design and prototyping tests are accomplished, the procurement/facilitization milestone will conclude with a Production Prove-Out test, where normally a complete lot of primers would be fabricated (i.e. for the 5.56mm caliber typically 2 million or more) and tested for full compliance to the specification. Based on the current modernization concepts already underway and those being proposed for LCAAP, the implementation of the MIC composition would be a relatively low risk effort. Because the leading candidate plans will automate the primer manufacturing process by incorporating a wet primer mix distribution operation, the MIC mixture can easily be substituted for the lead based mixture. One of the major drawbacks to the modernization of the primer line has been the inability to develop an acceptable lead styphnate based compound that is easily handled as a slurry. The MIC may have an advantage in this modernization study, as the current water based loading work is a slurry system.

Qualification of airborne CAD/PAD devices used by the Army, Navy, and Air Force is the responsibility of NAVAIR Program Office PMA 201 (Patuxent River NAS) and the CAD/PAD Joint Program Office (JPO) (POC: Mr. Paul McCafferty, NSWC/IHDIV).

For the CAD/PAD applications, the JPO is the authority for accepting the results of the demonstration plan for the Army and Air Force CADs and PADS deployed on board US Army and US Air Force aircraft. NAVAIR PMA201 is the authority for accepting the new primers into the Navy inventory and for foreign military sales.

There are a number of design factors that will affect the decision of adopting the primer in various applications, these factors are:

- Provide an environmentally benign replacement
- Meet all performance requirements of the applicable specifications
- Maintain form, fit and function
- Cost is comparable to that of the lead styphnate primers
- Provide required shelf life of end item
- Provide a drop-in replacement for lead based primers

The above stakeholder/end-users will evaluate several criteria to qualify the MIC replacement primer material and install the new MIC primer into existing weapons systems. Their decision-making factors are as follows:

- performance
- toxicity
- cost and availability of raw material
- safety during manufacturing and loading processes, handling, and storage
- interface with existing and future loading processes

Each of these factors is briefly discussed below.

Performance:

The demonstration addresses the performance requirements of the MIC primers and the selected applications. Meeting this performance is necessary for successful qualification of a replacement primer. The MIC composition was evaluated in the following applications:

- Cartridge 5.56mm Ball M855 (Army)
- PVU-1/A Ignition Device (Navy)

Affected components currently in production that are utilizing the No. 41 primer are the 5.56mm M855 Ball Cartridge.

The PVU-1/A percussion primer is used in 85 different CAD/PAD applications, each of which will be affected by replacement of the primer. A list of the affected CADs is included as Appendix A. Each one of these devices must meet the performance designated in its individual weapon specification. While there is no specific performance requirement for the primer in the CAD weapon specification, the replacement primer must have performance similar to or better than the PVU-1/A in order to properly perform its function in each CAD device. Thus, each MIC primer must be a drop-in replacement that maintains the same form, fit, and function of the original, and furthermore must also meet a 5 year installed life requirement. The cartridges selected for the demonstration are the CCU-51/A and CCU-61/A impulse cartridges, M90 and M93 delay cartridges, and the JAU-8/A25 initiator.

Toxicity:
The U.S. Army Center for Health Promotion and Preventative Medicine (CHPPM) will test MIC materials in a various toxicological test protocols and will provide reports summarizing the results to the stakeholders/end-users identified above.

Cost and Availability:
The cost of the manufactured primer must ultimately be comparable to those using the lead styphnate compositions presently in use. Also, commercially available raw materials must be available in sufficient quantities to meet anticipated production rates.

Safety, Handling, and Storage:
The replacement primers must meet the same safety requirements as the original. The safety of the manufacturing processes, handling, and storage for Navy devices containing energetic materials are evaluated by a Safety Review Committee, Project Readiness Review, conducted jointly by the NSWC/IHDIV Safety Department and Production Department management. These are thorough safety reviews that are required prior to manufacturing or handling energetic compounds at NSWC. After an initial review, they are conducted periodically.

Interface with Existing and Future Loading Processes

The No. 41 primer is currently made on a semi-automated assembly line operation. The basics (safety & performance) of the operation are based upon handling a de-sensitized, pliable, doughy material. This material is rolled into dies to form primer pellets that are ultimately consolidated into primer cups. To interface with the existing loading process, the de-sensitized MIC materials must be of a similar physical texture and consistency.

Full automation of the primer assembly is being investigated at this time. To fully automate the process, the primer material will have to be more of a slurry type mixture to facilitate the handling, metering and direct insertion into the primer cup operations. Again, the MIC based materials must have the mechanical properties to be compatible with these types of operations.

Because a water-based mixing process has been developed for the aluminum/bismuth oxide MIC compositions investigated under this program, it is anticipated that these compositions will be compatible with either the dough or slurry loading technique, and therefore provide a degree of flexibility with future developments in loading technology not possible with the lead styphnate primer compositions.

2. Technology Description

2.1 Technology Development and Application

Metastable Intermolecular Composite (MIC) material has the potential to replace the current conventional energetic composition in the initiation subcomponents of ammunition and cartridge actuated devices known as the percussion primer. The novel properties associated with nanostructure materials have resulted in the development of thermite-like formulations of energetic materials at the Los Alamos National Laboratory (LANL) [2,3]. These materials being of nano-sized particles offer the possibility of tunable energy release and high temperatures without appreciable gas generation and attendant high pressures. There are various examples of MIC applications that attracted a great deal of interest recently for weapon enhancement. One unique feature of MIC materials is its ability to produce particles hot enough to ignite a bed of propellant. Additionally, the MIC materials are impact sensitive which makes them a good percussion primer mix candidate. MIC can be utilized as an initiation composition for replacing the current established FA-956 and 5086 primer formulations which are based on lead styphnate, barium nitrate and antimony sulfide. The MIC mixture is an environmentally friendly, lead free composition.

In general terms, the MIC material is an engineered energetic composition consisting of a metal fuel (most often nano-scale aluminum) and metallic oxidizer that are exothermically reactive with each other. By utilizing nano-sized particles, the near atomic scale proximity of the reactants minimizes distances over which the fuel and oxidizer molecules must diffuse in order to reach each other, resulting in a dramatically increased reaction rate relative to that of conventionally sized pyrotechnic mixtures. Two of the most commonly used MIC compositions utilize molybdenum trioxide (MoO_3) or bismuth trioxide (Bi_2O_3) oxidizers, and have the following chemical reactions:

$$2Al + MoO_3 \rightarrow Mo + Al_2O_3$$
$$2Al + Bi_2O_3 \rightarrow 2Bi + Al_2O_3$$

For Army small caliber ammunition applications, the MIC primer must meet #41 primer all-fire and no-fire energy requirements and also ignite the propelling charge rapidly enough to meet the action time requirement for each individual cartridge application. The specific requirements are presented in more detail in Section 3.1.

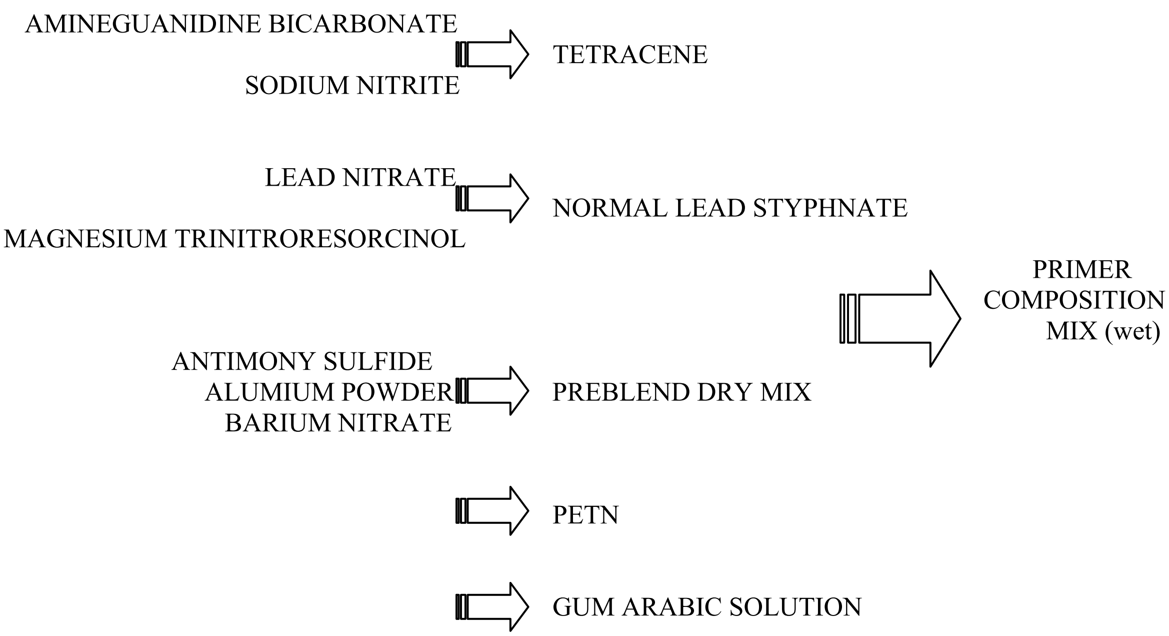
For CAD/PAD applications, the MIC primer must meet the PVU-1/A primer all-fire and no-fire energy specifications and also must function such that the performance requirements for each individual application are met. Because the applications chosen for the demonstration represent a cross-section of the CAD/PAD spectrum, the performance requirements vary considerably from one application to another. The specific requirements for each of the CAD/PAD demonstration applications are also presented in Section 3.1.

The current primer mix for all 5.56mm 7.62mm and 0.50 cal ammunition is the Frankford Arsenal composition FA 956. 20mm ammunition uses a primer mixture of slightly different amounts of the same basic components plus a carbon compound to make the mixture electrically conductive. These primer mixtures are manufactured by LCAAP. The manufacturing process used in producing the FA 956 primer mix is basically a five step process that includes the manufacture of trinitroresorcinol (TNR), lead styphnate, tetracene, pentaerythritol tetranitrate (PETN), wash, and a final wet mix operation.

- Lead styphnate is formed by mixing TNR with magnesium oxide to form magnesium trinitroresorcinol. The magnesium trinitroresorcinol is in turn mixed with lead nitrate to form lead styphnate.

- Other heavy metals chemical compositions besides lead that are added during the final mixing process of producing the FA 956 primer mix are antimony sulfide and barium nitrate.

- The following flow chart summarizes the current manufacturing process for the FA 956 formulation:



The wet-mixing procedure consists of the following steps (SOPs are read prior to any operation and are followed explicitly):

De-sensitized lead styphnate (approximately 25% water) is placed into the mixer. De-sensitized tetracene (approximately 30% water) is then added followed by the gum Arabic solution and the de-sensitized PETN (approximately 25% water). The mixer is then operated for an initial 2 minute cycle, paused for clean up and then operated for an additional mixing cycle of 2 minutes. After cleaning up the bowls of any ‘splashings’, the dry fuels (antimony sulfide and aluminum) are added to the mixture followed by the oxidizer (barium nitrate). The mixer is then operated for a 3 ½ minute cycle, paused for clean up and then operated for a final 3 ½ minute cycle. The finished wet primer mix is transferred to a conductive container and transported to the primer pelleting area.

Pellets are made by hand-pressing the wet primer mix onto a plate with holes that correspond to the number of primer cups that are to be filled. The pellets are then transferred to primer cups and the mix is consolidated. The anvils are then inserted into the consolidated mix and the finished primer is moved to a drying area for removal of water. After a period of time suitable to ensure the mixture is dry, the primers are tested for sensitivity and taken to the bullet assembly line to be inserted into cartridge cases

The PVU-1/A primer has been designed for use in aircrew escape systems for Army, Navy, and Air Force aircraft. Delay cartridges are used extensively in these systems, and because delay columns cannot tolerate high impact forces, it is necessary to use a primer mix that is less brisant than the FA 956 used in the #41 primer. In addition, to attain the high reliability required for man-rated systems, the PVU-1/A hardware has been designed for increased sensitivity to friction and impact. Thus, the output pressure generated by the PVU-1/A is roughly 25% of that for the #41, and the all-fire energy is considerably less (25.5 inch-ounces versus about 46 inch-ounces for the #41). These differences between the PVU-1/A and #41 primers highlight the difficulty in creating a common mixture which can be used in both.

The process for manufacturing the 5086 mix is specified in the PVU-1/A drawing package (NAVAIR 851AS110). The process is similar to that used for the FA 956, and is briefly summarized below:

- Inert ingredients (barium nitrate, calcium silicide, and antimony sulfide) are dried and sieved.
- Solvent-wet lead styphnate and tetracene are separately dried, weighed out to the correct proportions for the mix, and then re-wetted with ethanol.
- The bowl of a Hobart mixer is filled with ethanol, mixing speed is adjusted, the inert ingredients are added, and mixed for five minutes.
- The wet lead styphnate and tetracene are added separately and mixed for five minutes each.
- The wet mix is stored in polyethylene bottles for later use.
- Prior to loading, the wet mix is dried at 140 ºF for a minimum of 48 hours and then sieved through a 40 mesh screen.

PVU-1/A primers are hand-loaded in NSWC/IHDIV manufacturing facilities using the dry loading procedure illustrated in Figure 3. Lot sizes are typically 10,000 primers. After a lot has been completed 900 are withdrawn for sensitivity and dud testing in an NSWC ball-drop apparatus as per WS 21535B.

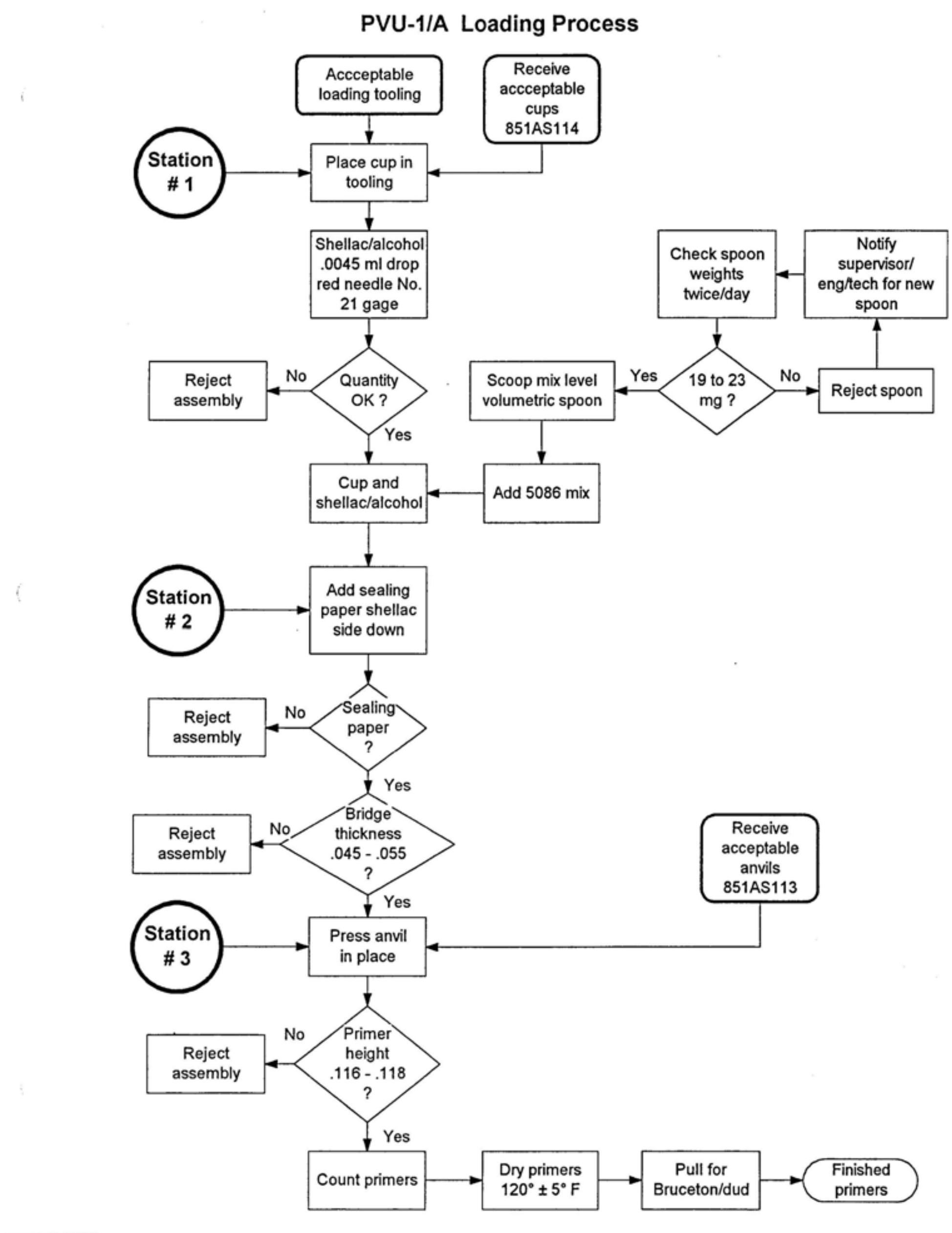
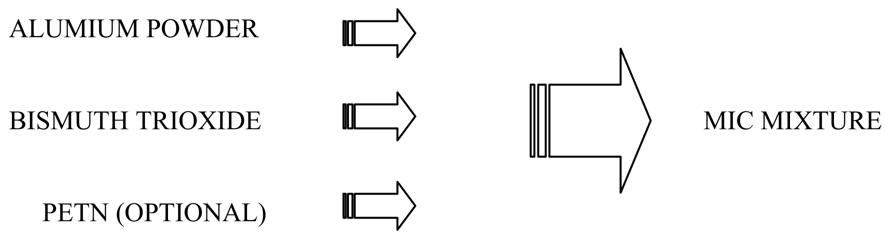


Figure 3 - PVU-1/A Dry Loading Process

The following flow chart characterizes the current MIC manufacturing process demonstrated at ARDEC, LANL and NSWC/IHDIV:



A brief description of the current procedure for manufacturing the MIC primer mix is illustrated in Figure 4. Recent technical advances in the MIC program have shown that MIC mixtures utilizing bismuth trioxide as the oxidizer can be wet mixed and loaded without significant degradation of the mix. Because of the inherent safety of this process, bismuth trioxide is currently being used as the oxidizer in all MIC development programs conducted at ARDEC and NSWC/IHDIV. Because of the sensitivity of the information, many of the details of the process have been omitted. Qualified organizations with a bona fide need-to-know can contact ARDEC or NSWC/IHDIV directly for access to this information.

The correct amounts of nano aluminum, oxidizer (bismuth trioxide) and other additives are placed into a mixing vessel. The optimum amount of solvent (hexane, cyclohexane or isopropyl alcohol) is added, and the composition is then mixed with either an ultrasonic probe or an ultrasonic bath. The mixing time is dependant on the method used. After mixing, the material is loaded into a primer cup, the anvil is inserted, and the loaded primer is placed into a vacuum oven for drying.

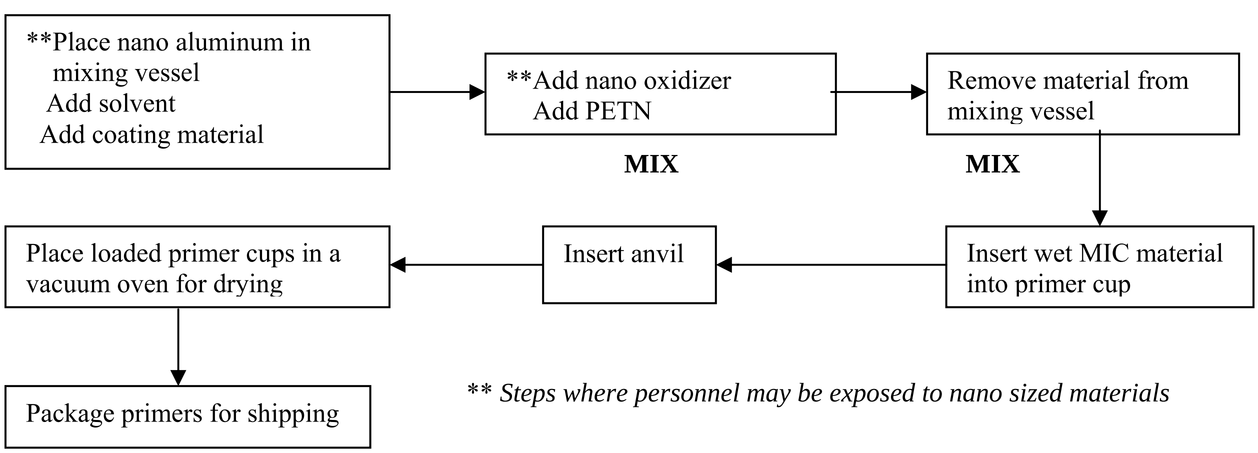


Figure 4 - Proposed MIC Primer Manufacturing Process

A chronological summary of MIC primer development at LANL (under ARDEC and SERDP funding), ARDEC, and NSWC/IHDIV is presented below:

FY 1998

- MIC Program Started
- ARDEC (Kapoor, Chung, Rocha) set up a small nano reactor in B-329. This was based on an RF induction plasma design made by LANL (Dr. Joe Martin)
- Established procedure at ARDEC to produce nano-aluminum powder.
- Established laboratory methods to measure nanoparticle characteristics
- NSWC evaluated ball drop sensitivity of LANL MoO_3 MIC primers.
- A decision was made to develop MIC Primers CAD/PAD applications

FY 1999

- The MIC Joint Working Group (MIC-JWG) was established (or enlarged)
- LANL developed a means to measure burn rate of MIC mix (combination of MoO_3 and nano-aluminum powder) for burning characteristics.
- MIC-JWG tasked to develop characterization techniques for nano-aluminum, oxidizer, and MIC mixtures
- Indian Head evaluated ball drop sensitivity of LANL MoO_3 MIC primers
- Evaluated LANL MoO_3 MIC primers in CAD/PAD applications.
- Indian Head developed UFAL production using resistive heating method.
- Initiated MIC primer loading study to improve primer sensitivity.

FY 2000

- ARDEC made small caliber primers with Al/MoO_3 compound
- ARDEC produced nano aluminum powders
- Initiated production of UFAL at NSWC/IHDIV
- Continued evaluation of LANL MIC primers in CAD/PAD Applications.
- Completed Primer loading parameters study and developed MIC primer loading techniques.

FY 2001

- Process Parameter Studies at ARDEC
  ARDEC wrote 2 reports on manufacturing nano-powders and establishing process parameters
- MCI-JWG developed standard methods of characterizing nano-powders(TEM, BET, helium pycnometer, particle size laser scattering analysis, X-ray diffraction, TGA, DSC, calorimeter, etc.)
- Initiated manufacturing of Indian Head primers.

FY2002

- ESTCP program initiated.
- Evaluated Indian Head MIC primer in CAD/PAD applications.
- Initiated evaluation of commercially available UFAL

FY 2003

- Completed design feasibility test series of NSWC/IHDIV MIC primers
- Completed evaluation of commercial UFAL.
- Initiated evaluation of gas producing additives.
- Initiated formulation/optimization of MIC compounds.
- Initiated wet loading technique of MIC primers

FY 2004

- Completed evaluation of gas producing additives to achieve consistent, low action time with #41 primers.
- Completed formulation/optimization study (patent pending).
- Selected final MIC formulation.
- Completed wet loading technique of MIC primers.
- Completed UFAL oleic acid coating study.
- Initiated water based loading process (patent pending)

FY2005

- Demonstrated feasibility of processing of the Al-Bi_2O_3 MIC in water suspensions.
- Developed efficient method of inhibition of Al oxidation by water and bismuth ions.

FY2006

- Developed and tested preparation of small caliber percussion primers using water based procedure of mixing of the Al-Bi_2O_3 MIC components in dense slurry and of a direct loading of the MIC slurry into the primer cups.
- Designed effective method of precise volumetric metering of the MIC mixture in water into the primer cups. Consecutive steps of the loading process are performed on material in the primer cup and are less susceptible to ESD and dusting.

FY2007

- Developed and tested preparation of CAD/PAD primers using water based procedure of mixing of the Al-Bi_2O_3 MIC components in dense slurry and of a direct loading of the MIC slurry into the primer cups.
- Developed an initial concept for a prototype manufacturing process based on loading primers on a continuous flow of primer material utilizing micro-mixer technology.

2.2 Previous Testing of the Technology

Nano powder based thermite mixtures have been routinely investigated in the various laboratories at both government and commercial facilities. Under the Joint Munitions Technology Development Program at Los Alamos National Laboratory, the use of nano aluminum powders was shown to be feasible. In a research and development program performed at ARDEC under SERDP funding, a solution for eliminating toxic components in the primer composition by using the nano powdered aluminum was developed [4].

Development efforts at NSWC/IHDIV concentrated on the use of commercially available aluminum, CAD/PAD applications, mixing and loading technology, and evaluation of various oxidizers. A list of reports, technical papers, and presentations generated in these endeavors is listed below in Section 7.4

2.3 Factors Affecting Cost and Performance

<u>Cost:</u>

The factors that influence the eventual cost of replacing existing lead-based primers with MIC counterparts are:

- The continued availability of the commercially manufactured nano-aluminum and bismuth trioxide. Having commercial firms manufacturing high quality, consistent materials that are the key components of the primer will be essential to the continued manufacture of affordable primers. The nano-aluminum and bismuth trioxide materials are unique to the MIC primers but the same factor can be applied to the standard primers, especially when environmental clean up related tasks are factored into the lead, barium and antimony based materials.
- Successful maturation and scale-up of a de-sensitizing process with water as the solvent. Any large costs associated with the re-facilitization of Lake City or Indian Head to make primers with a new material will seriously reduce the likelihood that a transition will occur. The current process uses a readily available, inexpensive solvent (water), thereby minimizing costs with respect to solvent purchase, collection and recycling back into the environment. Non-water based processes will add additional expenses to each of these areas.
- Compatibility with automated processes. The Government and the operator of LCAAP, Alliant Techsystems, Inc. (ATK), have been investigating the possibility of fully automating the primer assembly process. Mixed materials that can be easily and safely handled using automated equipment will reduce the labor necessary to produce these components.
- Mass production versus hand assembly. A cost factor unique to the CAD/PAD application is the potential commonality with a mass purchased item. Current PVU-1/A primers are manufactured in quantities of 3 – 5 hundred thousand per year, while the #41 is produced at a rate of approximately 1.3 billion per year. The high production rate of the #41 primer allows a large economy of scale on all of the principal parts driving the resultant per unit price down to a level not achievable at the lower production rate.

Performance:
There are a number of factors that influence MIC primer performance. These factors include the following:

- Particle size of aluminum and oxidizer. The particle size of the aluminum fuel can have a large impact on primer performance. Because the MIC composition must have intimate contact between fuel and oxidizer, and a large surface area is also desired, sub-micron particle sized fuel and oxidizer are required. Through testing, a size range of about 80 nanometers has been found to be optimum for this application.
- Particle Size Distribution. The sensitivity and burning rate of MIC compositions is strongly dependent on the particle size distributions of both fuel and oxidizer. Maintaining a uniform particle size distribution is essential to consistent primer performance.
- Mixing process. As with all chemical compounds, ensuring a uniform mixing of the ingredients is critical to achieving consistent, reliable performance. Proper weighing, solvating and ensuring the mixing/agitation cycle(s) are sufficient to create a homogeneous product are essential.
- Protecting the aluminum from oxidation. The extreme reactivity of nano-aluminum powder is one of the most significant properties of the MIC material. To maintain this reactivity, the aluminum powder must be passivated to protect it from oxidizing in the presence of air or water in the surrounding environment. This is an especially difficult problem in naval operations. An additional layer of an organic acid has been found to significantly increase the resistance to oxidation of the powder, even when in direct contact with water. Protecting the aluminum from oxidation for an extended period of time to prevent the MIC compound from losing sensitivity and thermal output will maintain performance and achieve the required shelf life for the end items.
- Solvent Removal. As with all primers, removal of the de-sensitizing compound (solvent) is required to restore sensitivity and output performance. Any remaining solvent could cause a misfire or worse, a hangfire where the round ignition is delayed until the cartridge is outside of the weapon system or the CAD/PAD device doesn't fire in sufficient time to activate the end system device.

2.4 Advantages and Limitation of the Technology

The advantage of this technology is that it utilizes common, non-polluting materials processed in unique ways that result in an initiation compound possessing sufficient energy and sensitivity to function in ammunition and cartridge actuated devices. The main components of the material are aluminum, bismuth and oxygen, all materials routinely found in everyday items. The small amount of PETN that makes up the remainder of the ARDEC primer compound is not common commercially, but is a material produced in reasonably large quantities for a number of military applications, including the existing primer compound. Additionally, commercial and other Government agencies are spending a relatively large amount of resources to start large scale production facilities for nano-particle sized metals.

The limitations of this technology are in the area of the processing of the materials to get to the end product state. Two areas are of particular concern and significant progress has been made in obtaining solutions. First, bare aluminum metal is extremely reactive and will react to oxidize instantly when exposed to oxygen. Early in the development of the nano-aluminum processing process development, it was realized that a thin passivation layer needed to be added to the nano-particles to prevent this oxidation and maintain the reactivity of the metal. However, this passivation layer will readily break down when the nano-particle is exposed to water, either liquid or vapor, again causing oxidation of the aluminum material, which renders the material inert. Recent work by Dr. Jan Puszynski, South Dakota School of Mines and Technology has shown that an additional thin layer of an organic acid can block the breakdown of the passivation layer without interfering with the ultimate reactivity of the aluminum [5] – [7]. Recent research by Dr. Puszynski has shown that protection by the organic acid lasts for several hours - ample time for mixing and primer loading operations. After loading, the primer can be dried and hermetically sealed into any desired cartridge. While the present procedure has been successful with small batches of primers, scale-up to large batches must still be investigated, as well as more firmly establishing the procedures by which the primers can be either stored for future use or immediately installed into cartridge cases.

The second area of concern is that the present state-of-the-art of the water-based mixing and loading process has not addressed scale-up to either large batches or continuous processing. More work in this area will be required to make the MIC material fully compatible with the high volume production equipment presently utilized in ammunition and CAD/PAD device manufacturing, as well as that envisioned for the future.

3. Demonstration Design

3.1 Performance Objectives

The ARDEC demonstration has verified that the ballistic performance of the 5.56mm #41 primers assembled with MIC formulation in a small caliber 5.56mm M855 cartridge is equal to or better than those using the current lead styphnate based primer formulation.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	Maintain specifications for original M855 ammunition.		
	Action Time	All values < 3.0 msec & x bar plus 3 sigma < 3.0 msec	Yes
	Chamber Pressure	48,335 – 48,449 psi	Yes
	Port Pressure	16,701 – 17,317 psi	Yes
	Velocity	2,968 – 2,976	Yes
	Function & Casualty	No metal parts breakup & no ammunition induced stoppages. Cyclic rate of 800 shots per minute	Yes No breakup or stoppage 762 – 798 rounds/minute
	2. Eliminate hazardous materials from the primer.	Zero percent lead, barium and antimony. in primer	Yes
Qualitative	1. No degradation in system performance.	Same operation and weapon function as with lead core ammunition.	Yes

Table 3 - 5.56 mm MIC Percussion Primer Performance Objectives

A brief description of each test to be performed is provided below:

- Action Time: Action time is defined as the total time from the strike of the primer to the projectile exit from the barrel. The action time is measured by starting a time counter with the firing solenoid actuation signal and stopping the counter by sensing a stimulus generated by the projectile exiting the barrel. Examples of stimulus usually used are the propellant muzzle flash, acoustic shock wave and projectile passing through an electrical break circuit.
- Chamber Pressure Test: Chamber pressure is defined as the peak pressure generated by the burning of the propellant at the chamber of the weapon. The pressure is measured by inserting a pressure sensitive sensor into the test barrel at a location adjacent to the cartridge case mouth. When the cartridge is fired the sensed pressure is transferred to and recorded on a high speed recording device.
- Port Pressure Test: Port pressure is defined as the peak pressure generated by the burning propellant at a location in the barrel where the pressure bleed port is located. Port

pressure is measured by inserting a pressure sensitive sensor into the test barrel at a location where the normal pressure bleed port would be.. When the cartridge is fired the sensed pressure is transferred to and recorded on a high speed recording device. To simplify test procedures, action time is often taken as the time differential between primer strike and the first appearance of pressure at the port, which occurs when the bullet passes the port. This approach ignores the time required for the bullet to travel from the pressure port to the muzzle, which is negligible compared to the time to reach the port.

- Velocity Test: Velocity is defined as the speed of the projectile when it exits the muzzle. Velocity is measured by registering the passing of the projectile past two sensing devices a fixed distance apart and counting the time required to traverse that distance. The sensing devices are located just downrange of the muzzle of the weapon. To ascertain the velocity uniformity and level of the ammunition and to determine if the average velocity and uniformity obtained complies with the requirements of the applicable specification.
- Function & Casualty Test: A function and casualty test is defined as all characteristics associated with firing that ensure that the ammunition can be expected to function satisfactorily in the service weapon for which it has been designed. The test is conducted by visually recording the functioning of the weapon plus firing the projectile through witness panels that will record the impact of any broken projectile parts.

The NSWC/IHDIV demonstration has verified that the ballistic performance of cartridges assembled with PVU-1/A percussion primers utilizing the MIC formulation are equal to or better than those using the current lead styphnate based primer formulation.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	1. Maintain specifications for original PVU-1/A	Meet Individual cartridge performance specifications	Yes
	2. Eliminate lead from the primer.	Zero percent lead. Material certification from vendors.	Yes
Qualitative	1. No degradation in system performance.	Same operation and system function as with lead-based primer.	Yes

Table 4 - PVU-1/A MIC Percussion Primer Performance Objectives

Specific performance objectives for the ARDEC M855 cartridges and the NSWC/IHDIV MIC primers and cartridges are given in the specification documents listed below. Copies of these documents may be obtained by writing to:

U.S. Army Armaments Research Development Center
ATTN: RDAR-QEM-D
Picatinny Arsenal, NJ 07806-5000

Michael Adams
Head, CAD/PAD Department
4393 Benson Road, Suite 120
Indian Head, MD 20640

MIL-P-46610E Primers, Percussion
MIL-C-63989C Cartridge 5.56mm Ball M855
SCATP-5.56mm Small Caliber Ammunition Test Procedures
WS21535 IGNITION DEVICE, (PERCUSSION), PVU-1/A (Navy)
MIL-C23288 Mark 4 Mod 2 Delay Cartridge (Navy)
WS20502 CCU-51/A Impulse Cartridge (Navy)
WS20508 CCU-61/A Impulse Cartridge (Navy)
MIL-C-60553 M-90 Delay Cartridge (Army)
MIL-C-46228 M-93 Delay Cartridge (Army)
WS18778 JAU-8/A25 Initiator (USAF)

3.2 Selecting Test Platforms/Facilities

Test Facilities: The demonstration tests were conducted at the ARDEC Armament Test Facility for the small caliber ammunition tests and at the CADTEST facility at NSWC/IHDIV for the CAD/PAD applications tests. Both facilities are equipped for and regularly perform similar testing. Testing conforms to Standard Test Procedures as outlined in the SCATP 5.56 ammunition and the LAT procedures found in the weapon specifications for the CAD/PAD devices referenced in Section 3.1. Testing at both facilities shall also be in accordance with ammunition specifications requirements and operational SOPs. The SOPs used in the CADTEST facilities are restricted to use in those facilities only, and cannot be copied or otherwise publicly disseminated. Accordingly, they are included below in Section 3.2.2 by reference only.

Test Platforms(5.56mm): All weapon platforms are currently fielded and in extensive use. The selected Army test weapon configuration is the M16A2 rifle. A single shot test barrel was used for collecting individual round performance data and an automatic weapon was used for full rate firing to test the ammunition interfaces with the weapon. The M16A2 weapon is representative of the 5.56 mm family of weapons, which are the M16A2, M249 Squad Automatic Weapon, and M4 carbine for the U.S. military forces. All three weapons are extensively used and represent a significant portion of the Army's small caliber firepower. Figure 5 shows the M855 cartridge, which was used in the demonstration tests. The Program Manager for Maneuver Armament Systems (PM-MAS) has cognizance over introduction of the MIC primer into these weapons.

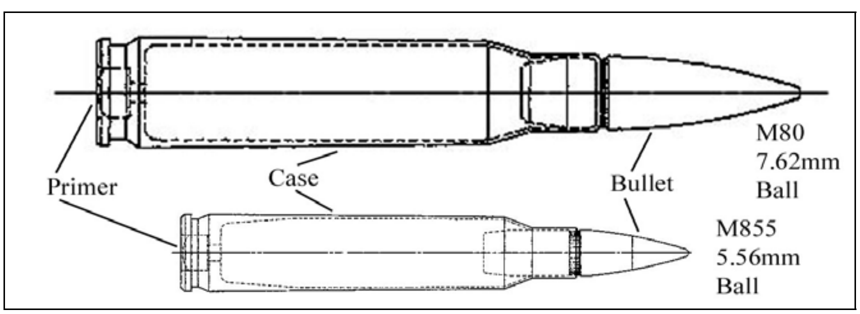
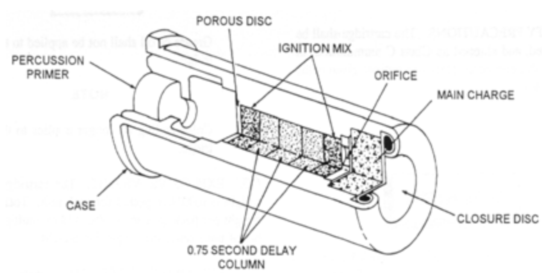


Figure 5 – M855 Cartridge

CAD/PAD Test Platforms: The PVU-1A percussion primer is used in the 85 cartridges listed in Appendix A. These cartridges are used by the Army, Navy, and Air Force, however all use the Navy PVU-1/A primer to initiate the pyrotechnic train in each. As explained in Section 1.4, responsibility for their acquisition therefore lies strictly with the Navy (NAVAIR and the CAD/PAD JPO). It would be cost prohibitive to demonstrate the PVU1/A primer performance in all 85 applications. Thus, the following cartridges were selected as a representative sample of the cartridge group, and they also include some worst case conditions regarding ignitability of the main (propellant) charge:

Mark 4 Mod 2 Delay Cartridge

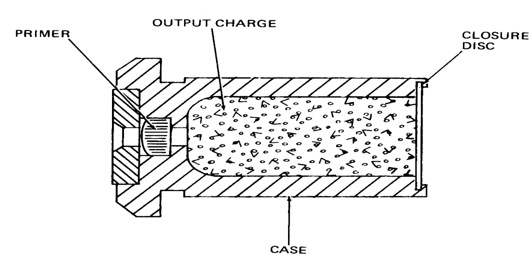
Performance Requirements
SOP: F84164 CH 2



The Mark 4 Mod 2 Delay Cartridge is a common delay cartridge used in many Navy CAD applications. The cartridge case sans delay and output charges is often used by the Navy as a test bed for PVU-1/A primers, and can be used in several different test fixtures. The PVU-1/A primer can be inserted into the cartridge case and then tested in one of the many test fixtures available to measure primer performance characteristics such as flash length, dudding, and ball drop sensitivity.

CCU-51/A Impulse Cartridge

Performance Requirements
SOP: F84214 CH 2



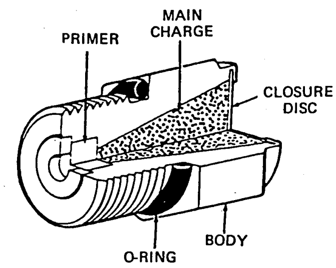
- Operating Temperature:
  - -65F to +200F
- Maximum Pressure:
  - 950 to 1350 psi
- Time to Peak Pressure:
  - 50 msec maximum

The CCU-51/A Impulse Cartridge provides pressure work for Navy ejection seats. The Hercules, Inc. HES 5808.23 ammonium perchlorate propellant is considered difficult to ignite. The primer output directly ignites the propellant in this application.

CCU-61/A Impulse Cartridge

Performance Requirements
SOP: F84127

- Operating Temperature:
  - -65F to +200F
- Maximum Pressure:
  - 450 to 900 psi

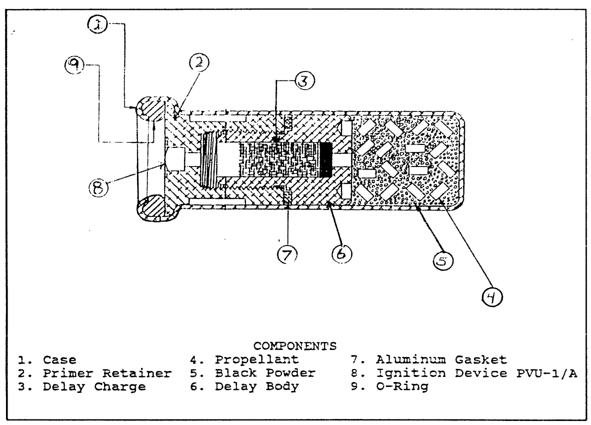


The CCU-61/A Impulse Cartridge provides pressure work for Navy ejection seats. The propellant is considered easy to ignite. The propellant consists of 27.2 wt%, lead azide, 8.8 wt% amorphous boron and 64 wt % barium nitrate. The primer output directly ignites the propellant in this application.

M-90 Delay Cartridge

Performance Requirements
SOP: F84066 CH 2

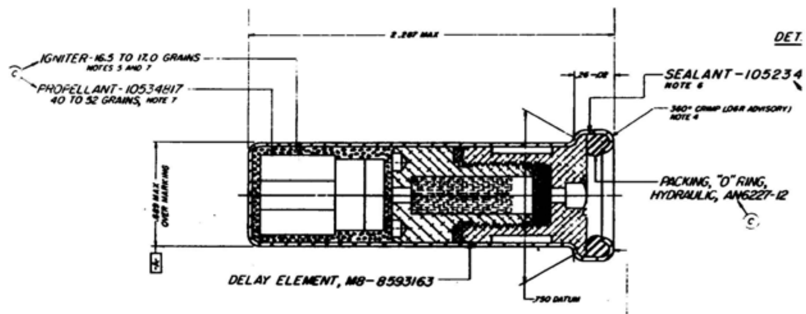
- Operating Temperature:
  - -65F to +200F
- Maximum Pressure:
  - 2000 to 2700 psi
- Ignition Delay:
  - 150 to 450 msec
- Time to Peak Pressure:
  - 12 msec maximum



The M-90 Delay Cartridge provides pressure work at a specific time for Army applications. The cartridge has a nominal 0.3 second ignition delay (see definition below) and is considered a short delay. The primer output ignites a T-10 delay composition consisting of 3-5wt. % boron and barium chromate.

M-93 Delay Cartridge

Performance Requirements
SOP: F84170 CH 2

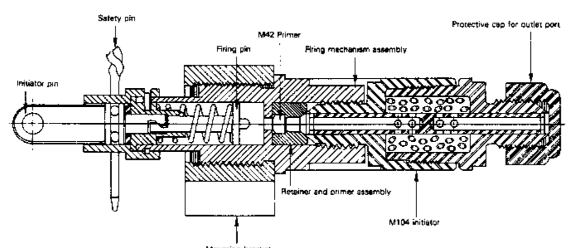


- Operating Temperature:
  - -65F to +200F
- Maximum Pressure:
  - 2300 to 3400 psi
- Ignition Delay:
  - 800 to 1300 msec
- Time to Peak Pressure:
  - 50 msec maximum

The M-93 Delay Cartridge provides pressure work at a specific time for Army applications. The cartridge has a 1.0 second nominal ignition delay (see definition below) and is considered a long delay. The primer output ignites a T-10 delay composition consisting of 3-5wt % boron and barium chromate.

JAU-8/A25 Initiator

Performance Requirements
SOP: F84249 CH2



- Operating Temperature:
  - -65F to +200F
- Minimum Pressure:
  - 300 psi
- Ignition Delay:
  - 40 msec maximum

The JAU-8/A25 Initiator accomplishes pressure work for USAF applications. The primer is assembled in an integral bulkhead configuration with isolates it from the rest of the device by a

thin (~0.006 inch) aluminum sheet. The primer output must penetrate the thin sheet of aluminum and travel down a flash tube that conveys the output energy to ignite the center of a propellant charge consisting of boron potassium nitrate pellets. This primer application is a unique configuration, and it is considered one of the most robust applications for primers.
A single NSWC/IHDIV CAD Test SOP (F84234) covers leak testing of all CAD devices. Primer ball-drop sensitivity testing in both steel die test fixtures and empty MK4 Mod2 cartridges is covered by SOP F84164.

3.3 Testing Platform/Facility History/Characteristics

The Armament Technology Facility is a full-service armament design and development laboratory for small and cannon caliber (through 40mm) weapon systems. It includes computer modeling and simulation capabilities, engineering workstations tied into rapid three-dimensional plastic prototyping (stereo lithography), electronic ties to robotically driven metal parts fabrication machinery, a model shop, in-house armament designers, plus a weapon assembly and repair facility. It also has four weapon validation bays with an environmental chamber capable of weather conditions between -65F to and +165F; two indoor ranges - the first 100 meters in length and the second 300 meters. The latter can accept a Bradley Fighting Vehicle System firing its primary armament; or an Abrams-series tank firing secondary armament. The 300-meter range also has a -65F to +165F environmental chamber for conditioning weapon systems through 40mm. Data acquisition and analysis capabilities include high-speed video (up to 150,000 frames per second). Available still photography with a billionth of a second shutter speed and forward looking infrared (FLIR) systems are examples of the on-hand, state of the art instrumentation.

The NSWC/IHDIV CAD Test facility conducts approx. 90% of the qualification, LAT, and surveillance testing of the Navy's CAD devices. The CAD Test facility also conducts approx. 5% of the Air Force CAD item testing. This translates into approx. 24,000 individual live ballistic tests per year. There are approx. 850 unique Navy CAD items and approx. 2000 unique Air Force CAD items. The breadth of the CAD testing performed at NSWC enables quick turn-around of Lot Acceptance Testing (LAT), Quality Evaluations (QE), Engineering Investigations (EI) and special tests required for both stock and issue items, as well as critical failure and crash investigations

3.4 Present Operations

Current #41 primers for 5.56 mm ammunition are manufactured at Lake City Army Ammunition Plant (LCAAP) using the process described in Section 2.1. Wastes generated by the synthesis process are treated at LCAAP and either recycled (mainly acids used in the pre-mixing of the materials) or recovered and then disposed of at a hazardous waste landfill by off-site commercial subcontractors. Manufactured ammunition is shipped to the U.S. Government and stored in magazines for use in either training or combat. Once fired, the byproducts of combustion are discharged into the burning propellant mass. The majority of these gases exit the barrel and are mixed with the air in the area of the shooter. Some small amount remains within the cartridge case which is ejected from the weapon and allowed to fall to the ground. In a training environment, the spent casing are collected and recycled to commercial firms for recovery and recycling.

PVU-1/A primers are manufactured both at NSWC/IHDIV and at OEA, Inc. in Fairfield, CA. Both facilities use the same basic manufacturing process that is described in Section 2.1, although the OEA process is partially automated. After manufacture, the primers are loaded into small plastic trays containing 100 primers. Each tray is inserted into a light cardboard box and sealed with tape to keep the tray from falling out of the box. Several boxes are then packed into a one-gallon aluminum paint can along with sufficient padding, after which the lid is installed in the usual manner. The paint cans are stored for later use in a magazine without temperature and humidity control. In a typical lot of 10,000 primers, 900 are immediately withdrawn from the lot for LAT.

When required for installation into CAD/PAD devices, the primers are either shipped to the cartridge manufacturer as GFM or to NSWC loading facilities. Once the cartridges have been loaded, they are shipped to their final destination in accordance with the individual cartridge specification referenced in Section 3.1.2, and stored in magazines without temperature and humidity control. There are no maintenance procedures associated with the primer.

Cartridges are normally expended in development, LAT, and surveillance testing; training; or military operations. The lead compounds produced in normal functioning of the primer are mostly pure lead (Pb), although small quantities of lead monoxide (PbO), and lead sulfide (PbS) are also produced. Those cartridges that are expended in testing at NSWC/IH are collected and thermally treated at the Strauss Avenue Thermal Treatment Point (SATTP) to react any explosive residue. Waste metal extracted from the SATTP is transported to the Solid Waste Recycler, where it is treated as minutely-explosive contaminated metal and “flashed” at temperatures up to 650 ºF to ensure that no explosive material remains. The metal is then disposed of by the Property Disposal Office through the Defense Reutilization and Marketing Office. These operations are carried out at under hazardous waste management plan IHDIVNAVSURFWARCENINST 5090.2D, which references all applicable SOPs.

Those cartridges that are expended in training and military operations are also collected to the extent possible - that is, downloaded from aircraft after completion of the mission. Obviously, they cannot be recovered if the aircraft is lost in hostile territory. Those that are recovered, however, are treated in the same manner as those expended in testing.

3.5 Pre-Demonstration Testing and Analysis

The basic development of the MIC primer for the 5.56 mm cartridge was accomplished under the earlier SERDP Program [4]. Some additional testing has been completed as part of this ESTCP effort to ensure commercial vendors for the basic ingredients can produce quality, repeatable materials. Additionally, some optimization of the basic formulation has been performed in an attempt to obtain a single compound that will meet both the 5.56 mm and CAD/PAD requirements. The engineering data generated as part of this evaluation was for comparative purposes to determine the best compound to meet the program requirements and not to establish a baseline performance. To date, a single MIC compound satisfying both 5.56 mm and CAD/PAD requirements has not been selected, and the demonstration tests were conducted with two separate MIC formulations. Both formulations utilized the same basic Al/Bi_2O_3 mixture along with a binder and processing aids, but that used for the 5.56 mm tests contained additional additives, most notably PETN. Utilization of the same basic MIC materials will allow for a common mixing process with any additional materials being requiring a single insertion and slightly longer mixing time to ensure homogeneity.

During the performance of the 5.56 mm demonstration firing, known performing (reference cartridges utilizing standard #41 primers) were fired to benchmark the performance of the test equipment. The demonstration rounds were fired from the same test equipment and their performance recorded. An additional small sample of the production lot of ammunition used for the 'harvesting' of the projectiles and propellant were also fired from the test equipment at ambient temperature. The mean and standard deviations of the data obtained from the demonstration rounds were then judged against the specification values as well as compared to reference and production rounds results.

Extensive DFT and DVT pre-demonstration testing of the replacement MIC primer took place during development efforts at NSWC/IHDIV. This testing included ball-drop sensitivity testing and tests with the CCU-51/A and CCU-61-A impulse cartridges and M90 and M93 delay cartridges. The cartridges were tested side-by-side with baseline cartridges from the same production lots, but which contained standard PVU-1/A lead styphnate primers. The cartridge data for a MIC primer utilizing an Al/MoO_3 formulation has been presented at various workshops and in technical journals (see the bibliography in Section 7.4). This data was used for development purposes only, and since the primer composition has been replaced with an improved Al/Bi_2O_3 formulation, <u>none of this data was used for comparison with data obtained in the demonstration tests.</u> Rather, the same approach was used in the demonstration tests as was done during DFT and DVT – that is, baseline data was collected using baseline PVU-1/A primers during the demonstration tests, and only this data was used for comparison with the MIC primer data.

3.6 Testing and Evaluation Plan

3.6.1 Demonstration Set-Up and Start-Up

The demonstration starts with the synthesis of the primer materials. Facilities and equipment used to accomplish this task remain in place at ARDEC in operational condition, so that no mobilization or demobilization is required. An in-process impact test is performed with each batch of material created to check to ensure that the synthesized material is sufficiently dry and well mixed. The impact test is a crude test utilizing a flat metal plate on which a small amount of the primer material is spread. A moderately heavy (≈16 ounces) flat steel striker plate is allowed to impact the material, crushing the primer mix in the process. If the primer does not rapidly react and create a loud, sharp report, it does not pass this test. If the material does not pass the impact test, the entire batch is scrapped in its entirety and stored as energetic waste, to be disposed of according to the local SOP.

After passing the impact sensitivity test, the material is loaded into #41 primer hardware. Again, the equipment and tools required for this task are operational. Once all primers have been assembled, a random sample is pulled and is subjected to a drop height primer sensitivity test to determine if they meet the minimum height for initiation requirement in the specification. The ball drop apparatus used at ARDEC is similar to that used at NSWC/IHDIV except that the primer products of combustion are directed into a small closed bomb.so that the primer pressure can be measured. Both devices use a magnetic suspension system to position a steel ball at the desired height. The ball weight and drop height correspond to the minimum all-fire energy requirement for the primer, which varies depending on the particular application. The ball drop apparatus is also used for sensitivity testing, wherein the drop height is varied to determine the all-fire and no-fire energies of the primer.

Passing of the test clears the primer lot for assembly into cartridges. Again, if the sample of primers does not pass the minimum initiation height test, the primer lot is then discarded and a new lot created. Acceptable primers are then loaded into cartridges and used in the demonstration, being subjected to what would normally be considered as the lot acceptance testing associated with primer function. The LAT procedures for the 5.56 mm cartridge used as the Army test platform are specified in the SCATP-5.56 referenced above. Those associated with primer function means, 1) any and all tests that are related to specific functionality of the primer, 2) as they relate to the delivered cartridge, 3)that would normally be conducted as part of a cartridge lot acceptance test. Cartridge action time (time from primer strike to bullet exit from the barrel), maximum peak pressure, maximum port pressure, bullet muzzle velocity, and weapon firing (cyclic) rate were the specific tests performed to meet this requirement. Tests like dispersion, waterproofing, metal parts integrity, ballistic match, etc. do not directly relate to individual primer functionality and were not included in the test program.

The ATF facility has the equipment to pull bullets from existing ammunition, reload and assemble 5.56 mm cartridges in place and maintains the equipment in an operational status for numerous other 5.56 mm test firings. The equipment required to conduct the test firing consists of a single shot test barrel, an M16A2 weapon, test stands to firmly hold each of the weapons in place while they are fired, sensing and counting electronics to record the analytical data generated during the demonstration and witness boards to show any impacts should a round not satisfactorily maintain structural integrity during the function and casualty. All of this equipment resides in the ATF and is placed in the firing range at the start of the test firings. The test set up is validated by firing 20 reference rounds from the single shot barrel and comparing the values obtained against the known values for the reference lot. Should any value be outside the allowable tolerance, troubleshooting procedures for the sensing and measuring equipment are initiated and the non-performing component replaced. The start up is then re-initiated with a new set of reference rounds to ensure proper performance of the set up.

All demonstration testing in NSWC/IHDIV test facilities is conducted under the SOPs referenced in Section 3.2. Both primer ball-drop sensitivity tests and full-up cartridge tests are conducted according to the test matrix presented in Section 3.6.6 (Table 3 – Test Matrix for MIC Primers Used in CAD/PAD Applications).

The ball-drop sensitivity test apparatus is permanently installed in CAD Test Bay 4 and requires no mobilization. Set-up procedures consist of mounting a sacrificial primer in the device and ensuring that the specified ball hits the firing pin squarely and on center. Ball height measurement is also re-calibrated at this time. Prior to the start of testing, the firing pin is inspected for wear, and replaced if necessary. All testing is done at room temperature with no temperature conditioning of the primers, which are transported to Bay 4 on the day of testing.

For cartridge testing, the LAT test fixture is retrieved from storage and set up in the selected test bay the day before testing is to begin, while all electronic diagnostic equipment is assembled on the morning of testing. All equipment is checked for calibration and appropriate serial numbers are recorded as per the SOP, which all operators are required to review prior to the start of testing. Cartridges are temperature-conditioned and readied for test according to the SOP. Initial testing for each cartridge begins with the PVU-1/A baseline units to ensure that the cartridge lot meets the appropriate Weapon Specification LAT requirements. If one or more baseline cartridges fail LAT, a decision is made by the test engineer as to whether to proceed with testing or to re-manufacture the lot.

3.6.2 Period of Operation

Manufacture and demonstration testing of MIC percussion primers, took place in facilities located at ARDEC (Picatinny Arsenal, NJ), NAVSEA (Indian Head, MD), and Innovative Materials and Processes (Rapid City, SD). The following timeline presents the highlights of these operations, which occurred during the time period from CY2005 to CY2007.

- March 2005 – 200 Al/Bi_2O_3 MIC primers were manufactured for the ESTCP demonstration test in #41 hardware at ARDEC using a solvent-based mixing process. The primers are stored in a desiccator for later use.
- May – August 2005 – A water based mixing and loading process for Al/Bi_2O_3 MIC primers is developed at IMP
- October 2005 – The IMP wet mixing and loading process is demonstrated at ARDEC and NAVSEA/IHDIV.
- November 2005 – November 2006 – Wet mixing and loading operations are investigated at ARDEC and NAVSEA/Indian Head, including performance evaluation of primers loaded in both #41 and PVU-1/A hardware.

- October 2006 – 525 Al/Bi_2O_3 MIC primers for the ESTCP demonstration test are manufactured at IMP in PVU-1/A hardware using the water-based mixing and loading process. The primers are stored in a desiccator for later performance testing and loading into Navy CADs for use in the ESTCP demonstration tests.
- October 2006 – The Al/Bi_2O_3 MIC primers successfully pass on-center and off-center Neyer sensitivity tests at IMP, allowing CAD loading operations to begin.
- October - November 2006 - 200 Al/Bi_2O_3 MIC primers were manufactured for the ESTCP demonstration test in #41 hardware at ARDEC using a water-based mixing and loading process. The primers are stored in a desiccator for later use in the ESTCP demonstration tests.
- October 2006 – July 2007 – Under contract to IMP, 160 PVU-1/A and 165 Al/Bi_2O_3 MIC primers are installed in loaded Navy CADs for use in the ESTCP demonstration tests. An additional 166 PVU-1/A and 176 Al/Bi_2O_3 MIC primers are installed in empty Mk4 Mod 2 cartridge cases for primer performance testing.
- January 2007 – ARDEC Al/Bi_2O_3 MIC primers are loaded into 5.56 mm ammunition and test fired in the ATF facility.
- August 2007 – IMP completes additional ballistic tests carried out in 5.56 mm ammunition with various Al/Bi_2O_3 MIC compositions in both #41 and PVU-1/A primer hardware.
- September 2007 – November 2007 – All loaded CADs and primed MK4 Mod2 cartridge cases are shipped from IMP to NSWC/IHDIV, where ESTCP testing is completed.

3.6.3 Amount/Treatment Rate of Material to be Treated

The test matrices for the ARDEC and NSWC/IHDIV demonstration tests are presented in Section 3.6.6. These matrices are slightly different than those appearing in the original test plan because of spare cartridges loaded for contingencies and the addition of some extra shots in 5.56 mm ammunition to look at some variations in the additives in the basic MIC composition. The ARDEC ATF tests were conducted with #41 primer hardware loaded with the MIC composition developed at ARDEC, while the NSWC/IHDIV cartridge tests were conducted with PVU-1/A hardware loaded with a similar MIC composition containing somewhat different additives, as developed for Navy applications. Ball drop sensitivity testing of the MIC primers used in the NSWC/IHDIV cartridge tests was performed in IMP facilities in Rapid City prior to final assembly of the cartridges. Additives were further investigated in supplemental ballistic tests conducted with 5.56 mm ammunition at IMP subcontractor Black Hills Ammunition, Rapid City SD. The quantities of MIC test articles expended in these test series are listed below.

Test Site	Configuration	Quantity	
ARDEC	5.56 mm M855 cartridge	180	
		Subtotal ARDEC	180
IMP	ball drop - die and cartridge case	317	
	5.56 mm M855 cartridge	51	
		Subtotal IMP	368
NSWC/IHDIV	MK4 Mod2 cartridge	27	
	CCU-51/A cartridge	43	
	CCU-61/A cartridge	33	
	M90 delay cartridge	32	
	M93 delay cartridge	33	
	JAU-8/A25 initiator	33	
		Subtotal NSWC	201
		Total MIC Primers	749

3.6.4 Operating Parameters for the Technology

Ammunition is, by design, self contained in terms of its ability to function in most environments. Most operational environmental changes do little to change the basic functioning of the cartridge. The propellant and primer contain all of the required fuels and oxidizers to function properly when stimulated. The two operational parameters that were varied during parts of the demonstration were the input stimulus and the temperature. The input stimulus was varied as part of the assembly check to ensure that the primers are not too sensitive to create a hazard yet sensitive enough to reliably function in the weapon system. The demonstration was fired at three temperatures to determine that the new primer does properly perform at the extremes of the normal operating band. For testing in 5.56 mm ammunition, chamber pressure, port pressure and velocity usually increase as the temperature increases, while action time has an inverse relationship, and usually decreases as operational temperature increases

Two types of demonstration tests were conducted at NSWC/IHDIV - primer performance and cartridge performance. The primer performance tests consist of ball-drop sensitivity, 13” dud test, off-center hits, and flash testing. The MIC primer must meet PVU-1/A all-fire and no-fire requirements and dudding performance in both a primer fixture (die) and empty MK4 Mod2 cartridge cases. These requirements are listed in Table 3. The sensitivity tests were conducted under computer control using a 30 unit Neyer Sensitivity Test and Analysis technique rather than the 50 unit Bruceton called for in WS21579. The Neyer method has replaced the Bruceton method for much of the sensitivity testing performed at NSWC/IHDIV. The Neyer software produces a 50% all-fire height and standard deviation, and these are used to calculate all-fire and no-fire energies as per WS21579. There are no formal requirements for off-center hits and flash, and these tests are normally done for information purposes only. Flash testing consists of measuring the length and time duration of the luminous flash from the primer with a high-speed camera. These tests were also performed with standard PVU-1/A lead styphnate primers to provide direct side-by-side comparison.

For the cartridge tests other than those conducted in empty MK4 Mod2 cases, primer performance is not measured directly. The success or failure of each shot is judged on whether each individual cartridge meets the LAT performance specified in the Weapon Specification (and also the SOP) for that cartridge. These performance parameters include one or more of the following, depending on the specific cartridge under test:

- ignition delay
- peak pressure
- time to peak pressure

While these parameters are usually averaged, either in Excel spreadsheets or by hand, to obtain means and standard deviations for the lot, this is done for informational purposes only, and is not required by the SOP.

3.6.5 Experimental Design

The experimental design plan for MIC primer validation was developed with one simple concept in mind, the lead styphnate and antimony sulfide currently used in the Army #41 and Navy PVU-1/A primers are to be totally eliminated through use of the MIC composition, which contains only bismuth trioxide, aluminum, small amounts of processing aids, and possibly PETN. This goal will be accomplished with a one-for-one replacement of the component that contains these materials - the primer. Thus, upon replacement of the standard FA-956 and 5086 primer mixes with the MIC composition will ensure that the toxic materials associated with those mixes never reach the environment. This will eliminate one source of toxic material pollution at manufacturing, testing, and training facilities for the weapons systems that use the primers.

Since the MIC composition will be loaded into existing hardware, the MIC primer will be a drop-in replacement for the #41 and PVU-1/A, and no system modifications will be required. To validate the primer, then, it is only necessary to show that the MIC primer meets all #41 and PVU-1/A performance specifications, and performs satisfactorily in the various weapons systems in which it will be used. Thus, the demonstration plan for each application is taken directly from the applicable system specification. All tests being performed as part of the demonstration are standard evaluations that are conducted as part of lot acceptance testing of systems that are currently being produced and fielded. For demonstration purposes, it is not feasible to test the MIC primer in every potential application, as there are multiple weapons that fire the 5.56 mm ammunition and currently 85 weapons systems in the Navy inventory alone that use the PVU-1/A. Upon successful demonstration of the MIC primer in the #41 and PVU-1A primers, the technology could be transferred to other, larger primers, as well, which would decrease toxic material pollution even further.

The original test plan devised for demonstration purposes had one goal in mind - that a single MIC primer composition would be tested in both Army and Navy hardware, and no additional optimization of the composition would occur during the demonstration. In the time period between finalization of the test plan and its implementation, the MIC composition was changed from an Al/MoO_3 formulation to an Al/Bi_2O_3 formulation. As is described in Section 2.4, the aluminum is coated with a material that protects it from degradation during mixing with the Bi_2O_3 in water. The Bi_2O_3 is naturally impervious to water and requires no protection. This change was made to take advantage of the enormous benefits of a water-based mixing and loading process which is possible with only the Al/Bi_2O_3 formulation. The major advantage of the Al/Bi_2O_3 formulation lies in that it can be mixed and loaded in a wet process. This process allows for a simple liquid metering loading procedure which can easily be automated. More importantly, however, the wet mixing process is inherently safer than dry mixing as it eliminates the possibility of inadvertent initiation during loading operations due to friction, impact, or electrostatic discharge. Inadvertent initiations, while not rampant, have occasionally occurred during mixing, loading, and disposal operations with the Al/MoO_3 primer. Also, the Al/MoO_3 composition cannot be mixed in water because the MoO_3 takes up the water in the form of a hydrate, which drastically increases ignition energy and reduces thermal output.

Although research on MIC compositions has continued at ARDEC and NSWC/IHDIV, there was too little time available to complete the necessary research and development to select a single composition for both Army and Navy applications. Thus, the major portion of the demonstration tests were conducted with two MIC compositions, the only difference being the addition of a small percentage of PETN in the Army primer used in 5.56 mm ammunition. To take a quick look at some variations to the MIC composition, a limited number of tests with 5.56 mm ammunition were added to the test program. The research effort is still continuing, however, and it is expected that in the future, a single MIC composition will be used in both Army and Navy primers. This optimism is partly based on observations that the Al/Bi_2O_3 composition puts out a higher pressure than the Al/MoO_3 composition used earlier, and therefore the task to design one primer composition suitable for both Army and Navy primer applications is now somewhat easier. PETN and other additives were introduced to the MIC formulation when the Al/MoO_3 composition was the only MIC composition available and higher output pressures were desired.

The detailed ARDEC and NSWC/IHDIV demonstration test program is provided below in the tables in Section 3.6.6. These plans list the parameters to be measured in the demonstration tests (these are also listed in Section 3.6.4 above) and the values and ranges of these parameters that the MIC primers and full-up cartridges must meet to satisfy the various Weapons Specifications are listed in the tables in Section 3.1 For the 5.56mm tests, the primers must meet the requirements of MIL-C-63989C Cartridge 5.56mm Ball M855 when tested in accordance with the procedures specified in the SCATP-5.56mm Small Caliber Ammunition Test Procedures.

For the NSWC/IHDIV tests, the MIC primers must meet the PVU-1/A specifications listed. For the CAD applications, five cartridges were selected for demonstration testing that span the broad spectrum of Navy CADs currently in use. To further broaden the approach, CADs employed in both Army and Air Force airframes were also included. While these devices are used by

Services other then the Navy, the CAD/PAD Joint Program Office at NSWC/IHDIV is the design agent for all these devices and is responsible for their production. Specifically, the MK4 Mod2 cartridge case is commonly used as a PVU-1/A testbed, and were used as such in the demonstration tests to evaluate MIC primer performance directly (all-fire and no-fire energy, dudding) while installed in a cartridge (albeit empty). The remaining fully-loaded cartridges were selected to include Navy impulse cartridges (CCU-51/A and CCU-61/A), Army delay cartridges (M90 and M93), and one Air Force igniter (JAU-8/A25). The impulse cartridges were chosen to include one that has an output charge that is considered to be difficult to ignite (CCU-51/A), while the other has one that is considered easy to ignite (CCU-61/A). Likewise, the Army delay cartridges were chosen to include one with a relatively short delay (M90) and one with a long delay (M93). The JAU-8/A25 igniter was chosen because it has a long flash tube, which the primer combustion products must traverse to successfully light the output charge.

3.6.6 Product Testing

Testing of the 5.56 mm primers was conducted in the end item (fully assembled cartridges) as shown below. A modified (quantities only) Sensitivity and First Article ballistic test evaluation was performed to record the actual performance of these test rounds compared to reference rounds of cartridges utilizing standard lead styphnate-based #41 primers. The test rounds were taken from the same reference lot and refitted with MIC primers. Thus the data taken with the MIC primer rounds is directly comparable to the reference rounds. This approach is a slight deviation from the original test plan, and was implemented because the propellant charge of the reference rounds was not optimized to meet the 3020 ft/sec LAT muzzle velocity requirement at ambient temperature. Two different MIC primer lots were tested – one lot manufactured in 2005 with a solvent-based mixing and loading process, and the other a lot manufactured in 2006 using the water-based mixing and loading process. This is a deviation from the original test plan, which called for testing of a single lot only. For each EPVAT test, ninety single shot rounds were evaluated in a MANN test barrel for each MIC primer lot as per the SCATP. Also for each primer lot, fifty rounds (20 single shot, 30 burst mode) were tested for F&C in an M16A2 rifle. No formal sensitivity tests were conducted with the two MIC primer lots prior to loading into cartridges.

	Test Plan (Each Primer Lot)			**Detailed Description**
	Ambient	-65°F	+125°F	SCATP Reference
- Action Time\1	50	20	20	Section 7, pg 37
- Velocity\1	50	20	20	Section 7, pg 37
- Pressure, Chamber\1	50	20	20	Section 7, pg 37
- Pressure, Port\1	50	20	20	Section 7, pg 37
- Function & Casualty\2	50			Section 10, pg 53

\1 Electronic Pressure, Velocity Action Time performed with standard MANN test barrel, test data is collected simultaneously for each round shot.

\2 50 as part of the Function & Casualty test with an M16A2 rifle following the procedures outline per MIL-C- 63989C

Supplemental ballistic testing of MIC primers was carried out under contract to IMP at test facilities at Black Hills Ammunition in Rapid City, SD. The purpose of the tests was to evaluate some modifications to the MIC composition, fire PVU-1/A hardware in 5.56 mm ammunition, and to examine MIC primer performance with non-standard propellant. All primers tested were manufactured at ARDEC using the IMP water-based mixing and loading procedure. All testing was done in single shot mode in a test fixture similar to that used in the ARDEC ATF. One difference was the method used to estimate action time, which did not conform to SCATP practices. For the IMP tests, action time was determined by firing at an instrumented screen 13.333 feet from the muzzle of the gun and assuming constant bullet velocity to establish when the bullet left the barrel. The test matrix is given in Table 5. The measured performance of the MIC primers was compared to that obtained with a reference lot of 10 #41 standard primers.

Primer Hardware	Shots	PETN Load	Propellant	Measured Performance
#41	10	None	Standard	Velocity/Action Time
#41	10	Nominal	Standard	Velocity/Action Time
#41	10	Double Load	Standard	Velocity/Action Time
PVU-1/A	10	None	Standard	Velocity/Action Time
PVU-1/A	5	None	0.4 Grain Increase	Velocity/Action Time
PVU-1/A	6	None	Fast Burning	Velocity/Action Time

Table 5 – Supplemental Ballistic Tests

The test matrix for the NSWC/IHDIV demonstration tests is given in Table 6. As has already been explained in preceding sections of this report, the NSWC/IHDIV demonstration test procedures are specified by the SOPs given in Section 3.2, and the corresponding performance specifications listed in Table 3. With one exception, the test procedures and performance requirements specified in these documents were followed explicitly. The one exception is the Bruceton analysis specified in WS21535B to determine the all-fire and no-fire energies for each primer lot. A newer alternative method, the Neyer Sensitivity Test and Analysis (SENTEST*) method, was used instead of the Bruceton. This method, which is often used in lieu of a Bruceton at NSWC/IHDIV, utilizes statistical analyses generated during the test to establish the next test level (ball drop height) rather than choosing levels a priori, as is done with the Bruceton method. At NSWC/IHDIV the Neyer technique has been found to be more accurate than the Bruceton, and requires fewer primers. The Neyer method establishes a 50% all-fire level and standard deviation for the primer lot under test. These two parameters are then used to determine the all-fire and no-fire energies for each primer lot in accordance with the mathematical procedures specified in WS21579.

* Neyer Software, Cincinnati, OH

Item	MIC Primer	Mk4 Mod2 Case	CCU-51/A	CCU-61/A	M-90	M-93	JAU8/A25
DODIC		M499	MF31	M28	M207	M209	M758
DOD Branch	Navy	Navy	Navy	Navy	Army	Army	USAF
Specification Pass/Fail Criteria	modified WS21579	MIL-C23288	WS20502	WS20508	MIL-C-60553	MIL-C-46228	WS18778
Top Assembly DWG	3205AS271	2518446	845AS150	851AS125	8593312	8593314	11731737
Quantity Assembled	175	78	43	33	32	33	33
Non Destructive Leakage Radiographic			 43 43	 33 33	 32 32	 33 33	 33 33
Destructive Flash Test 13" Dud Primer Sensitivity	 25 60	 30 25 23					
Off Center Hits 0.010 0.020 0.030	 30 30 30						
Performance Firings Conditioned @ 200 +/-5 F 70 +/-5 F -65+/-5 F			 16 11 16	 12 10 11	 11 10 11	 11 11 11	 11 10 12
Visual Inspection	See Below	See Below	See Below	See Below	See Below	See Below	See Below
Radiographic	See Below	See Below	See Below	See Below	See Below	See Below	See Below
Leakage (cc/s)	NA	NA	$< 1.0x10^{-5}$	$< 1.0x10^{-5}$	$< 1.0x10^{-5}$	$< 1.0x10^{-5}$	$< 1.0x10^{-5}$
Primer Sensitivity	All-fire Energy ≤25.49 inch oz; No-fire Energy ≥3.84 inch oz	All-fire Energy ≤25.49 inch oz; No-fire Energy ≥3.84 inch oz	NA	NA	NA	NA	NA
13" Dud	No Misfires	No Misfires	NA	NA	NA	NA	NA
Peak Pressure P_{max} (psig)	NA	NA	950-1350	450-900	2000-2700	2300-3400	>300
Time to P_{max} (ms)	NA	NA	≤50	NA	≤12	≤50	40
Ignition Delay (s)	NA	NA	≤0.050	≤0.050	0.150-0.450	0.85-1.30	NA

Table 6 – NSWC/IHDIV Demonstration Test Matrix

For cartridge LAT testing, there are no statistical methods used to establish performance. Each individual cartridge tested must meet the LAT specification – not the average for the lot. For the present tests, performance at each temperature was averaged, however, to provide a meaningful comparison of the MIC and standard PVU-1/A primer lots. All testing except for primer flash was conducted in the LAT test fixtures specified in the SOPs, while flash testing was conducted in an existing test fixture designed specifically for this test.

To provide baseline data for comparison with the cartridges containing the MIC primers, additional tests were carried out with cartridges from the same production lot, but containing standard PVU-1/A primers. In this way, side-by-side tests were conducted with the MIC and PVU-1/A lots, allowing direct comparison of the results. Some or all of the tests with the PVU-1/A primers were conducted first to determine if each cartridge lot was within specification. All cartridges tested (both MIC and PVU-1/A primed) were found to meet their respective LAT specifications.

The number of cartridges tested differs slightly from the original test plan because unused spares manufactured for contingency were fired whenever possible. Also, 33 CCU-51/A cartridges were manufactured with a small aluminum disc covering the output end of the primer spithole to keep potential primer dust from falling into the output charge. Such dusting was thought to be possible due to vibration during shipment of the loaded cartridges. An extra 10 CCU-51/A cartridges, were manufactured without the disc and added to the test program to allow investigation of its effectiveness. The control lot of PVU-1/A primed cartridges also did not contain the disc.

3.6.7 Demobilization

The demobilization of the synthesis, assembly and firing facility for the 5.56 mm primer will be a simple cleaning and temporary storage of the tools and equipment used to do the work, as additional materials synthesis, assemblies and firings utilizing the test platforms will occur at this site.

Demobilization of the ball-drop and MK4 Mod2 test fixtures used for Navy MIC primer testing is not required, as this equipment is permanently installed in Bay 4 of the CAD Test facilities at NSWC/IHDIV. Demobilization of the LAT test fixtures used for cartridge testing is controlled by the SOPs listed in Section 3.2, and consists essentially of cleaning each test fixture and placing it in storage for future use.

3.7 Selection of Analytical/Testing Methods

For demonstration testing at ARDEC, standard statistical methods were used as outlined in the SCATP-5.56. The SCATP dictates how the data is accumulated and how it is tabulated. For the NSWC/IHDIV tests, procedures and requirements are called out by the respective individual military specification for the primer and each cartridge. These are listed in the table in Section 3.6.6. The one deviation from the primer specification is that ball-drop sensitivity testing was conducted with a Neyer Sensitivity Test and Analysis rather than a Bruceton (see Section 3.6.6). Test operators and data acquisition personnel employed in NSWC/IHDIV CAD Test facilities have been performing the specified LAT tests for many years, and are therefore extremely well experienced in performing all the tests required for the demonstration. The Data Quality Assurance/Quality Control Plan developed for the demonstration test appears in Appendix B.

3.8 Selection of Analytical/Testing Laboratory

The bulk of the demonstration test program was conducted in ARDEC and NSWC/IHDIV facilities under the procedures and requirements as specified above in Section 3.7. Because the MIC primers used in NSWC cartridges were manufactured at IMP, it was convenient to set up a ball-drop sensitivity test apparatus there to immediately confirm proper primer sensitivity.

Except for some minor differences, the IMP apparatus was an exact copy of that used at NSWC/IHDIV, and the same analytical methods (Neyer sensitivity) were used.

The supplemental ballistic testing performed under contract to IMP and performed at BHA (see Section 3.6.6) was conducted with a MANN barrel test apparatus that was similar to that used in the ARDEC ATF with similar port and chamber pressure instrumentation. The experimental technique used at BHA to establish action time was only approximate, however, so that the test data therefore can only be considered as approximate. Because these tests are supplemental to the demonstration, the data is informational only, and neither use nor non-use of it has any effect on the outcome of the demonstration.

4. Performance Assessment

4.1 Performance Criteria

The 5.56mm M855 cartridge demonstration tests were performed with two sets of cartridges:

- A reference lot of sample cartridges utilizing standard #41 primers
- The demonstration cartridge lot utilizing MIC primers

Both lots have the same performance criteria, some of which are specified in MIL-C-63989C and are listed below in Table 7. Additional primary and secondary performance criteria that are unique to the demonstration tests are also listed there. The demonstration tests consisted of firings of the reference and demonstration lots in a gun that was instrumented to measure the performance parameters listed in Table 7.

For the NSWC/IHDIV demonstration, two types of tests were conducted:

- MIC Primer performance in PVU-1/A hardware
- Performance tests of five cartridges employing MIC primers

The rationale for the tests is covered in Section 3.6.5, and the complete test matrix for the demonstration is presented in Table 6, in Section 3.6.6. The primer performance tests are designed to demonstrate primer performance directly via the performance criteria listed below in Table 8. The specific values to be obtained are found in Table 6. The sensitivity and dud tests are performed in both a test fixture in which the primer under test is inserted in a die, and in empty Mk4 Mod2 cartridge cases. The flash tests, also performed in empty Mk4 Mod2 cartridge cases, have no performance requirements, and are performed for information purposes only. Off-center hit tests are performed to determine all-fire and no-fire energies under conditions simulating worn equipment. There are no specific pass/fail criteria for this test, either, although excessive sensitivity (e.g., increase in all-fire energy) to off-center hits would be of concern.

Performance criteria for the five cartridges selected for demonstration testing are listed in Table 9. Although three different types of cartridges are being tested (the rationale for their selection is given in Section 3.6.5), the major requirement for all is primarily the same. Each individual cartridge containing a MIC primer must meet the performance called out in its individual Weapon Specification. The specific values for each are given in Table 6, Section 3.6.6. Thus, the introduction of the MIC primer into each weapon system must be transparent to the end user. Additional primary and secondary performance criteria, unique to the demonstration tests, are also contained in Tables 8 and 9

Performance Criteria	Description	Primary or Secondary
Product Testing	Must pass all product tests listed below: 5.56 mm M855 Cartridges: Extreme Temperature Function (-65°F to +125°F) Action Time Velocity Chamber Pressure Port Pressure Function & Casualty	Primary
Hazardous Materials	The MIC Primer will eliminate the lead styphnate, barium nitrate and antimony sulfide from the primer composition. Diphenylamine and dibutylphthalate remain in the propellant composition.	Primary
Factors Affecting Technology Performance	Quality of the starting aluminum material Efficiency of the mixing process Residual moisture content of the primer mix Input energy from the firing pin	Secondary
Process Waste	Small amounts of the basic materials (aluminum and bismuth trioxide) are expected to remain in the storage containers. The anticipated disposal will be to discard the containers without cleaning as the nano-aluminum will rapidly oxidize in the presences of air rendering it harmless and the bismuth trioxide is not hazardous. Small amounts of unmixed PETN plus any residue from the primer mixture will be carefully collected per the applicable SOP as they are energetically hazardous. Disposal will be by open burning per the applicable local SOP.	Secondary
Reliability	Munitions are considered one time devices and, as such, do not require maintenance. The operating conditions extremes of the demonstration are not expected to affect the performance of the technology. A weak or broken firing pin spring within the weapon being used could negatively affect the functional reliability of the primer by not providing sufficient impact energy to initiate the primer compound.	Primary
Ease of Use	The MIC primer technology can be synthesized and loaded by chemist and engineering technicians normally trained to handle current primary explosive. The operation of the weapon system will use the same skills taught for the current ammunition.	Secondary
Versatility	The basic MIC primer technology should be useable in most chemically initiated propelling devices. Slight variations in the percentages of materials may be required to adjust sensitivities or output as required by the end using system.	Secondary
Maintenance	Munitions are one time devices requiring no maintenance. Loading and synthesis equipment will require the same maintenance as the current process.	Secondary
Scale-Up Constraints	Large scale manual loading techniques should be feasible with a water or hexane solvent system. The main change will be determining if sufficient hexane is used to require collection of the evaporation products. Extremely large scale, automatic production will depend on interfacing with a currently planned upgrade to the existing facility. The water based solvent technique is the consistency of a slurry, which is more amenable to this type of loading technique and may have distinct advantages in its integration into a high speed automated process.	Secondary

Table 7 – 5.56 mm M855 Cartridge Performance Criteria

Performance Criteria	Description	Primary or Secondary
Product Testing		
Primer Sensitivity	The MIC primer must meet PVU-1/A all-fire and no-fire energy requirements.	Primary
13" Dud Test	All 25 primers must fire successfully.	Primary
Off Center Hits	Compare performance of MIC Primer to traditional lead styphnate based primer.	Primary
Flash Test	This test is conducted for information only.	Secondary
Hazardous Materials	The MIC Primer will eliminate the lead styphnate, barium nitrate and antimony sulfide from the primer composition.	Primary
Process Waste	Fired primers and MK4 Mod2 cartridges will constitute process waste, which will be hazardous from both explosive and toxic residue standpoints. Lead pollution will be eliminated with MIC primers. Levels will be on the order of milligrams for each. Disposal operations are described in Section 3.4.	Secondary
Factors Affecting Technology Performance	The demonstration test matrix is designed to determine if the MIC composition can be transitioned to PVU-1/A (lead styphnate) primer hardware without a reduction in sensitivity and dudding performance (see Product Testing above).	Primary
Reliability	Non-temperature related reliability issues are addressed in product testing (see above). Temperature related issues are investigated in flash tests, but there are no requirements.	Primary
Ease of Use	The MIC primer is designed as a drop-in replacement for the PVU-1/A, with identical operational ease of use. No specific ease of use testing has been built into the test program. This factor will be important regarding mixing and loading operations, which are also not addressed in the test program	Secondary
Versatility	The basic MIC primer technology should be useable in most chemically initiated propelling devices utilizing percussion primers. Slight variations in the percentages of materials may be required to adjust sensitivities or output as required by the end using system.	Secondary
Maintenance	Munitions are one-time devices requiring no maintenance. Synthesis and loading equipment will require the same maintenance as the current process.	Secondary
Scale-up Constraints	Scale-up of MIC mixing and loading is not addressed in the demonstration tests, but will eventually have to be considered for large scale primer production	Secondary

Table 8. Navy MIC Primer Performance Criteria

Performance Criteria	Description	Primary or Secondary
Product Testing		
Cartridge Firing	Each cartridge must meet Weapon Specified performance over the temperature range of –65 F to 200 F (see Table 3, Section 3.6.6).	Primary
Leakage	Leak rate must be less than 1.0×10^{-5} cc/sec.	Primary
Hazardous Materials	The MIC Primer will eliminate the lead styphnate, barium nitrate and antimony sulfide from the primer composition. Lead, chromate, and perchlorate compounds will remain in the main charge of the cartridges (see Section 3.2.2).	Primary
Process Waste	Fired primers and cartridges will constitute process waste, which will be hazardous from both explosive and toxic residue standpoints. Trace amounts of both burned and unburned primer and main charge components will remain (see above). Lead pollution from the primer will be eliminated with MIC primers. Levels will be on the order of milligrams or less for each. Disposal operations are described in Section 3.4.	Secondary
Factors Affecting Technology Performance	The demonstration test matrix is designed to determine the temperature sensitivity of the cartridges and compare it to those using the standard PVU-1/A lead styphnate primer.	Primary
Reliability	Reliability data will be collected during product testing by averaging the performance of each cartridge at each of the three test temperatures and computing standard deviations. There is no requirement for this data, and it will be collected for information only.	Secondary
Scale-up Constraints	Scale-up of MIC mixing and loading is not addressed in the demonstration tests, but will eventually have to be considered for large-scale primer production. Water-based wet mixing and loading processes for bismuth trioxide primer compositions are expected to scale up to large production lot sizes without difficulty.	Secondary
Ease of Use	The MIC primer is designed as a drop-in replacement for the PVU-1/A, with identical operational ease of use. No specific ease of use testing has been built into the test program. This factor will be important regarding mixing and loading operations, which are also not addressed in the test program	Secondary
Versatility	The basic MIC primer technology should be useable in most chemically initiated propelling devices utilizing percussion primers. Slight variations in the percentages of materials may be required to adjust sensitivities or output as required by the end using system.	Secondary
Maintenance	Munitions are one-time devices requiring no maintenance. Synthesis and loading equipment will require the same maintenance as the current process.	Secondary

Table 9. Navy Cartridge Performance Criteria

4.2 Performance Confirmation Methods

All test equipment, test procedures, and data collection and reduction methods required to perform the 5.56 M855 demonstration tests are specified in SCATP-5.56 and MIL-C-63989. The gun used to fire the cartridges is instrumented with chamber and port pressure transducers plus an electronic chronograph that is used to establish the time that the primer is struck by the firing pin. Bullet velocity screens are positioned downstream of the muzzle to obtain the bullet velocity at a distance of 78 feet from the muzzle. The chronograph and transducers are used to measure action time, which here is defined as the sum of the times required for primer ignition, burning of the propellant, and for the bullet to reach the barrel port. The port pressure transducer is only 6.0 inches from the gun muzzle, so that using either bullet time to port or time to muzzle exit is essentially equivalent with regard to action time, the difference being on the order of 0.2 msec

Once the performance of the reference lot has been determined and conformance with MIL-C-63989C established, the demonstration lot is fired. The specific performance required for the demonstration lot per MIL-C-63989C is listed in Table 10 along with the performance actually obtained in the demonstration test. Detailed analysis, including the results of the supplemental tests, is presented in Section 4.3.

For the NSWC/IHDIV demonstration tests, the MIC primer must meet performance specified in WS21535B. The performance confirmation methods for the primer tests are listed in Table 11. The following definitions apply to primer sensitivity:

All Fire Energy = (Hbar + 5S) x W (inch-ounces)
No Fire Energy = (Hbar – 2S) x W (inch-ounces)
Hbar = 50% all-fire height (inches)
S = standard deviation (inches)
W = weight of ball (ounces)

The values of Hbar and S were determined from the Neyer Sensitivity Test and Analysis software employed in a 30 unit test under SOP F84164 CH 4. All methods and procedures used to establish the values of Hbar and S are specified in the SOP, which all test personnel are required to read and sign. Use of the Neyer method is a deviation from the SOP, which calls for a Bruceton. The SOP also requires all test equipment used to be in calibration. The 13” dud test is conducted under the same SOP and WS21579 requires all 25 primers to fire successfully, with no misfires. Sensitivity and dud testing was conducted in both a primer fixture (steel die) and empty MK4 Mod2 cartridge cases. Table 11 also contains the actual MIC primer performance obtained in the demonstration, while analysis and discussion of the results is presented in Section 4.3.

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product Testing	Must pass individual product tests specified in SCATP-5.56 and MIL-C-63989, summarized below.	Physical test in accordance with SCATP-5.56,	
Extreme Temperature Function	1. Average velocity shall not decrease by more that 250 feet per second (fps) from the average velocity of the sample cartridges conditioned at 70°F. 2. The average chamber pressure shall not vary from the chamber pressure of the sample test cartridges by more than 7,000psi. The average chamber pressure shall not exceed 63,700psi. 3. The average port pressure shall not vary by more than 2,000psi from the average port pressure of the sample cartridges, but not to be less than 14,600psi. 4. Action time shall not change from the sample cartridges. 5. The cartridges shall function without casualty at ambient temperature and at the temperature specified in the test.	Physical test in accordance with SCATP-5.56 & MIL-C-63989	Performance similar to standard M855 rounds
Action Time Match	1. Ballistic match with the M855 is to be no more than 3 milliseconds	EPVAT. & MIL-C-63989	1.39 msec solvent 1.22 msec water
System Accuracy	1. Both average vertical standard deviation and the average horizontal standard deviation shall be no greater than 6.8 inches at 600 yards, or alternatively, no greater than 1.8 inches at 200 yards.	Physical test in accordance with SCATP-5.56 & MIL-C-63989	Not tested: Hand assembly is not representative of the current high speed assembly process
Barrel Erosion	1. The average life of the barrel shall not be less than 10,000 rounds.	Physical test in accordance with SCATP-5.56	To be completed as part of final cartridge qualification testing
Waterproof	1. Each cartridge shall not emit more than one air bubble when subjected to an internal pressure of 7.5 psi for a minimum of 30 seconds.	LCAAP Test Requirements	Not tested: assembly was by hand, not automated machine
Hazardous Materials	1. No lead in the projectile	Certification of material	All materials were free of lead

Table 10 - 5.56 mm M855 Cartridge Performance and Testing Requirements

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product Testing	Must pass individual product tests specified in WS21535B and summarized below.	Physical test in accordance with SOP F84164 CH 4	
Primer Performance Flash Test	1. All-Fire energy must be less than or equal to 25.49 inch-ounces 2. No-fire energy must be greater than or equal to 3.84 inch-ounces 3. No misfires in 13" dud test 4. All-fire and No-fire Energy with off-center hits 5. Measure flash length and time duration	Neyer Sensitivity Test Neyer Sensitivity Test 13" Dud Test Neyer Sensitivity Test High Speed Camera	16.47 in-oz 7.24 in-oz No misfires See Section 4.3 See Section 4.3
Hazardous Materials	1. No lead in the MIC primer mix	Certification of material	All primer mixes were lead-free

Table 11 - Expected and Actual Performance For Navy MIC Primers.

For the NSWC/IHDIV cartridges assembled with MIC primers, the following test procedure was followed:
Each cartridge was subjected to pre-test inspection consisting of the following:

- **Visual Inspection**: Cartridges shall be free of the following visible defects: burrs, dents, deep scratches, split or cracked edges, damage to closure, sharp edges, defective sealant application around the crimped or sealed areas and all other defects which could conceivably prevent entry into firing chamber or adversely affect ballistic performance.

- **Radiographic Examination (X-Ray**): All assembled cartridges shall be examined. The cartridges shall be positioned on their sides for the most revealing exposure. Cartridges having any observable imperfections in assembly shall be cause for rejection.

For each test, the cartridge was mounted in the LAT test fixture specified in the appropriate SOP, which generally consists of a closed bomb and a primer firing mechanism. The exact experimental arrangement differed somewhat for the various cartridges tested, but they were largely the same, with the volume of the bomb being the major difference. In each fixture, the firing mechanism contained a force gauge to establish when the primer was struck, and a pressure transducer mounted in the closed bomb was used to monitor pressure versus time. The following definitions apply:

Ignition Delay: The time from actuation of the firing mechanism to the start of pressure rise in the bomb

Time to Peak Pressure (Pmax): The time from start of pressure rise to maximum pressure

The test results were analyzed and subjected to the pass/fail criteria for ignition delay, peak pressure, and time to peak pressure contained in the Weapon Specification document for each cartridge. The expected performance and performance confirmation methods (SOPs) are listed below in Tables 12 – 16.

Performance Criteria	**Expected Performance Metric (Pre demo)**	**Performance Confirmation Method**	**Actual Performance (Post demo)**
Product Testing	Must pass individual product tests specified in WS20502 and summarized below.	Physical test in accordance with SOP F84214 CH 2	
	1. Peak pressure must be 950 to 1350 psi 2. Maximum time to peak pressure is 50 msec	Closed bomb	892 – 1088 psi 8.4 – 36.1 msec
Leakage	<1.0x10^{-5} cc/sec	SOP F84234	All passed
Hazardous Materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

Table 12 - Expected and Actual Performance For CCU-51/A Impulse Cartridges

Performance Criteria	**Expected Performance Metric (Pre demo)**	**Performance Confirmation Method**	**Actual Performance (Post demo)**
Product Testing	Must pass individual product tests specified in WS20508 and summarized below.	Physical test in accordance with SOP F84127	
	1. Peak pressure must be 450 to 950 psi	Closed bomb	816 – 1034 psi
Leakage	<1.0x10^{-5} cc/sec	SOP F84234	All passed
Hazardous Materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

Table 13 - Expected and Actual Performance For CCU-61/A Impulse Cartridges

Performance Criteria	**Expected Performance Metric (Pre demo)**	**Performance Confirmation Method**	**Actual Performance (Post demo)**
Product Testing	Must pass individual product tests specified in MIL-C-60553 and summarized below.	Physical test in accordance with SOP F84066 CH 2	
	1. Ignition delay must be 0.150 to 0.450 seconds 2. Peak pressure must be 2000 to 2700 psi 3. Maximum time to peak pressure is 12 msec	Closed bomb	0.288 – 0.342 sec 2,415 – 2,565 psi 8.4 – 12.0 msec
Leakage	<1.0x10^{-5} cc/sec	SOP F84234	All passed
Hazardous Materials	1. No lead in the MIC primer mix	Certification of Material	All MIC primers were lead-free

Table 14 - Expected and Actual Performance For M90 Delay Cartridges

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product Testing	Must pass individual product tests specified in MIL-C-46228 and summarized below.	Physical test in accordance with SOP F84170 CH 2	
	1. Ignition delay must be 0.85 to 1.30 seconds 2. Peak pressure must be 2300 to 3400 psi 3. Maximum time to peak pressure is 50 msec	Closed bomb	1.02 – 1.18 sec 2865 – 3105 psi 32.6 – 42.0 msec
Leakage	$<1.0x10^{-5}$ cc/sec	SOP F84234	All passed
Hazardous Materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

Table 15 - Expected and Actual Performance For M93 Delay Cartridges

Performance Criteria	Expected Performance Metric (Pre demo)	Performance Confirmation Method	Actual Performance (Post demo)
Product Testing	Must pass individual product tests specified in WS18778 and summarized below.	Physical test in accordance with SOP F84249 CH 2	
	1. Peak pressure must be greater than 300 psi 2. Maximum time to peak pressure is 40 msec	Closed bomb	414 – 531 psi 15.0 – 32.5 msec
Leakage	$<1.0x10^{-5}$ cc/sec	SOP F84234	All passed
Hazardous Materials	1. No lead in the MIC primer mix	Certification of material	All MIC primers were lead-free

Table 16 - Expected and Actual Performance For The JAU8/A25 Initiator

4.3 Data Analysis, Interpretation and Evaluation

For the EPVAT tests conducted in the ARDEC ATF, the reference lot used for performance comparison was shot twice (20 rounds before each of the MIC lots and 3 rounds after). Although the same reference lot was used for both, these have been designated as Ref 1 and Ref 2. The performance of the cartridges using the MIC primer lot manufactured in 2005 with the solvent-based mixing and loading process was compared to that for Ref 1. Similarly, the performance of the cartridges using the MIC primer lot manufactured in 2006 using the water-based mixing and loading procedure was compared to that for Ref 2. Although corrected performance metrics were computed for each lot according to the procedures mandated in SCATP-5.56, the actual values were used for all performance comparisons. These appear as calculated mean values and standard deviations for each lot in Table 17, and are plotted in bar chart format in Figures 6 – 9. A complete listing of the data is included in Appendix C.

Temperature	Primer Lot	No. Rounds	Peak Pressure		Action Time	Velocity
			Case Mouth (psi) Mean (Std Dev)	Port (psi) Mean (Std Dev)	(microsec) Mean (Std Dev)	(ft/sec) Mean (Std Dev)
Ambient	Reference 1	20	48,335 (931)	16,701 (320)	856 (30)	2,976 (15)
"	MIC Solvent	50	48,913 (882)	17,290 (326)	1,229 (39)	2,971 (17)
-65F	"	20	42,928 (1647)	16,881 (316)	1,364 (135)	2,858 (31)
+125F	"	20	50,604 (1790)	17,389 (326)	1,153 (79)	3,020 (27)
Ambient	Reference 1	3	48,616 (313)	16,931 (186)	843 (10)	2,990 (14)
Ambient	Reference 2	20	48,449 (794)	17,317 (344)	850 (44)	2,968 (17)
"	MIC Water	50	51,848 (1518)	17,527 (311)	1,072 (50)	3,012 (26)
-65F	"	20	45,499 (1759)	17,222 (272)	1,203 (94)	2,893 (40)
+125F	"	20	54,907 (1672)	17,405 (338)	1,076 (41)	3,073 (29)
Ambient	Reference 2	3	49,596 (1147)	17,289 (298)	876 (8)	2,978 (31)

Table 17 – Single Shot ATF Test Results For 5.56 mm Cartridges
(Reference Rounds Use Standard No. 41 Primer)

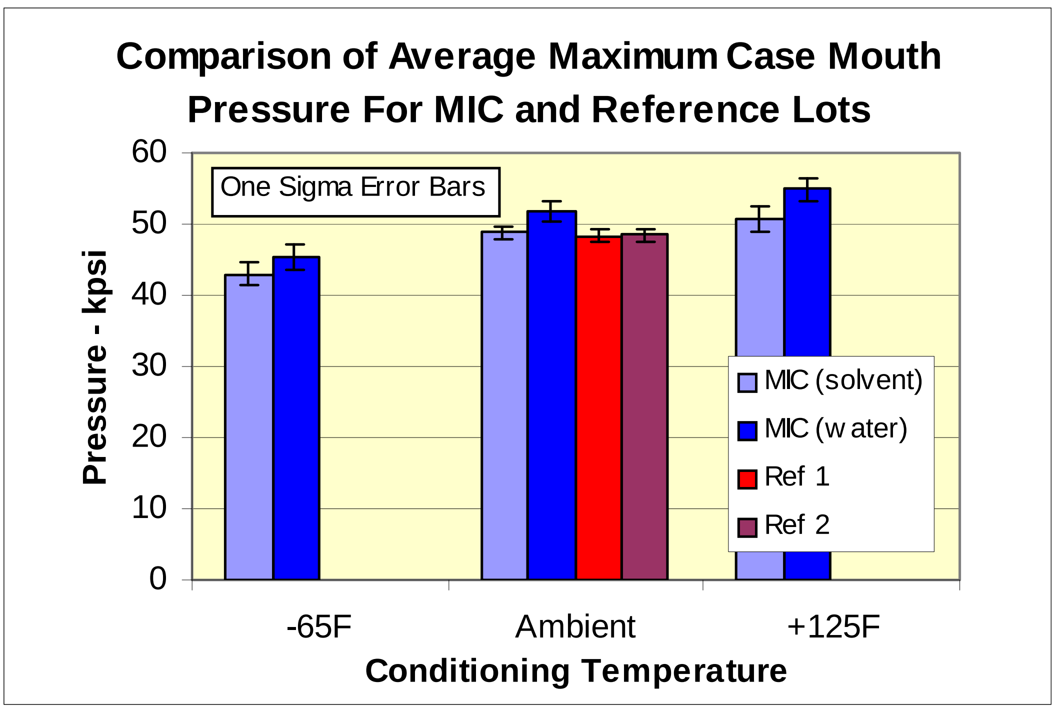


Figure 6 – Maximum Case Mouth Pressure in ATF EPVAT Tests

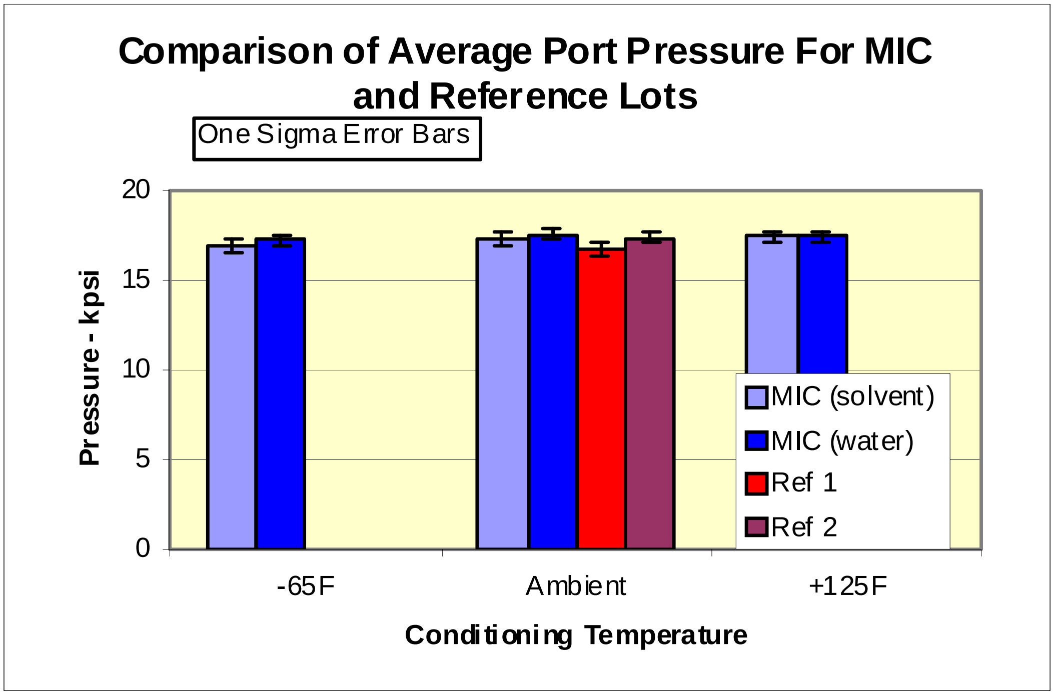


Figure 7 – Maximum Port Pressure in ATF EPVAT Tests

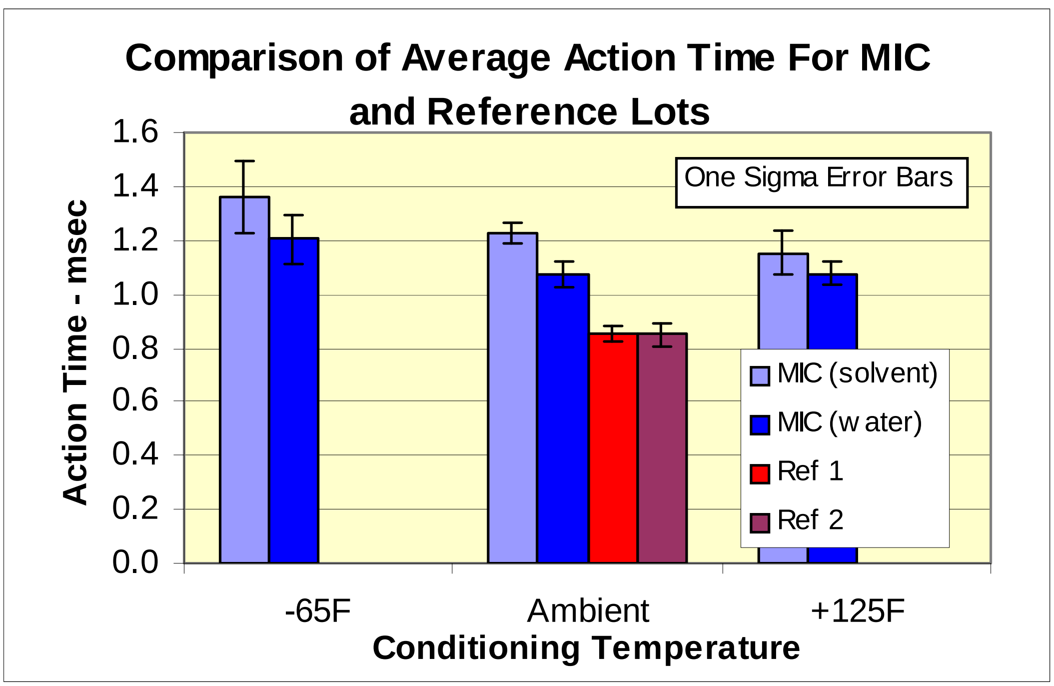


Figure 8– Action Time in ATF EPVAT Tests

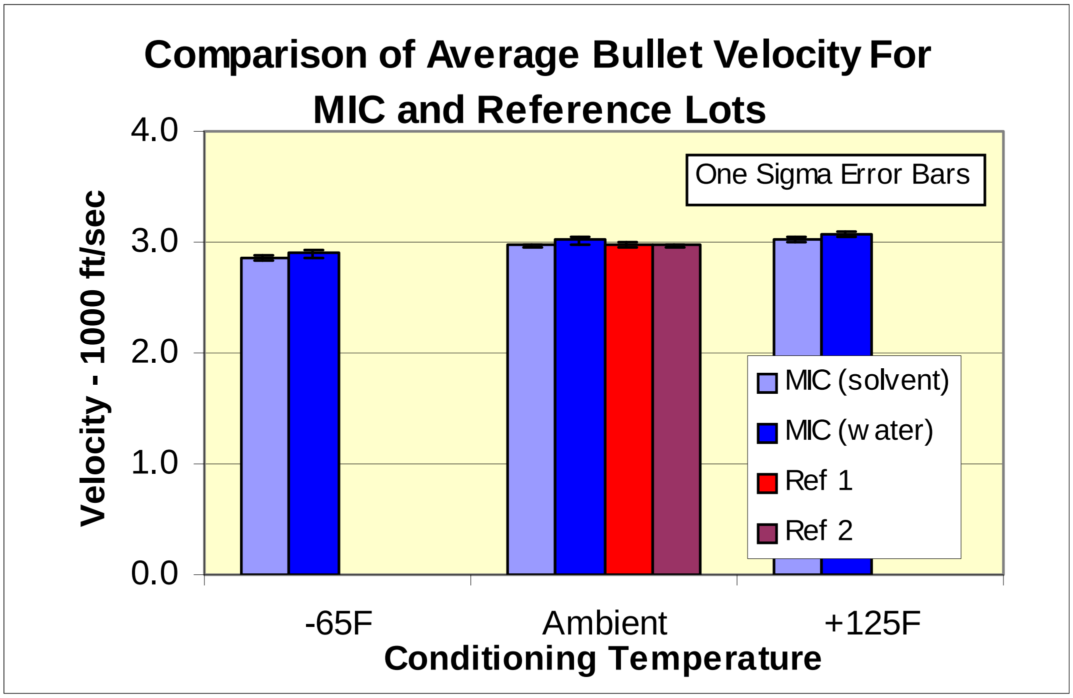


Figure 9 – Bullet Velocity in ATF EPVAT Tests

Since the reference rounds were fired only at ambient temperature, direct comparison of the MIC primed rounds with the reference rounds can only be made at this particular temperature. The hot and cold rounds do show how temperature affects the MIC primed rounds, however. Figures 5 – 8 show that at ambient temperature, the cartridge performance with the solvent based MIC primers is about the same as the reference rounds with regard to case and port pressure and bullet velocity, while the action time is longer. The 3-sigma action time is still much less than the 3.0 msec requirement, however. Also at ambient temperature, the cartridge performance with the water-based MIC primers is slightly better than the reference lot, except for action time, which is somewhat shorter than that for the solvent-based composition, but still longer than that for the reference rounds. These results indicate improved ignition of the propelling charge with the water-based MIC composition compared to the solvent-based composition.

Both MIC compositions show the expected temperature effects (lower pressure, lower bullet velocity, and slightly longer action time at lower temperature), but the primers using the water-based mixing and loading procedure are affected to a lesser degree. Again, this appears to be the result of improved ignition of the propelling charge. Thus, the water-based primers would be preferred for use, not only on a performance basis, but also because of their enormous manufacturing advantages.

The function and casualty tests were carried out in the ATF using an M16A2 rifle fired in both single shot and burst modes. The single shot tests (20 rounds each) showed bullet dispersion with the MIC primers to be equivalent to that of standard M855 rounds. As summarized in Table 18, the 3 to 4 round burst mode cyclic rates obtained with the two MIC primer compositions were slightly lower than those obtained with the standard primers. It is not immediately obvious why the rates of fire are somewhat lower with the water-based MIC primers, which exhibit superior performance to the solvent-based primers in single shot mode.

Two primer no-fire events occurred during the ATF tests – both with the water-based MIC primers. The first occurred during the EPVAP tests at –65F, while the other occurred during the burst mode M16A2 shots at ambient temperature. No positive identification of the cause for either has been identified, however. Inspection of the firing pin indents in each primer revealed what appeared to be normal indents for each. Hence, either low primer load or handling-induced fracture of the primer charge leading to reduced charge weight, are thought to be the most likely causes.

Primer Lot	No. Rounds	Rate rd/sec	Primer Lot	No. Rounds	Rate rd/sec	Primer Lot	No. Rounds	Rate rd/sec
M855	10	815	MIC solvent	19	798	MIC water	17	770
		823			773			762
		825			776			780
					791			766
					796			768
Mean		821			787			769
Std Dev		5			12			7

Table 18 – M16A2 Cyclic Rates of Fire in Burst Mode

Test results of the supplemental ballistic tests of water-based MIC primers proceeded at BHA according to the test matrix in Table 5. The primers were manufactured and loaded into M855 cartridge cases at ARDEC, and prior to being shipped to BHA, sensitivity tests on the two lots containing PETN (in #41 hardware) were conducted using the Neyer method and software in the ARDEC ball-drop apparatus. The results of the Neyer tests, presented in Table 19, indicate reduced standard deviation with the double PETN load, which leads to higher reliability. The results obtained with the nominal PETN load are considered acceptable, however.

PETN Loading	$H_{50\%}$	Std Dev	0.001 Reliability	0.999 Reliability
	(in)	(in)	(in)	(in)
Nominal	7.67	1.65	2.58	12.77
Double	6.99	0.666	4.93	9.05

Table 19 – Effect of PETN Charge Weight on Primer Sensitivity
(1.94 ounce ball, #41 primer hardware, M855 cartridge cases)

The objectives of the tests were to examine the effects of PETN addition to the MIC primer composition, primer hardware (#41 vs PVU-1/A), and changes to the propelling charge on ballistic performance. The MANN barrel and pressure instrumentation used for the tests was similar to that employed in the ATF at ARDEC, although the method used to determine action time was different. Instead of being measured directly, the method of determining the time at which the bullet left the gun muzzle was to assume constant bullet velocity once it left the barrel. Thus, knowing the distance from the muzzle to the screen and the time at which the bullet reached the screen, it was possible to calculate when the bullet left the muzzle. A final report issued by IMP contains the details of the test procedures used, as well as copies of the data sheets obtained for each of the seven primer lots tested. The section of the report describing the tests at BHA and including copies of the data sheets is included in Appendix C. A summary of the bullet velocity and action time data appears in Table 20.

Comparing the action times obtained at BHA at ambient temperature (Table 20) with those obtained in the ARDEC ATF (Table 17) shows that the BHA measurements run about 0.05 msec higher, consistent with the lower velocities obtained there. The BHA results show little or no benefit to a moderate addition of PETN, while the double load of PETN showed a modest reduction in action time, about half of what was required to match the reference lot. Additional testing with larger lots is needed to absolutely confirm the BHA results at higher PETN loads. It should be recognized, however, that the ATF tests (Table 17) were conducted with moderate PETN loads in the MIC composition, and the longer action times observed there are consistent with the BHA results. Thus, there is reason to believe that MIC action times can be reduced to the reference lot levels with the addition of suitable amounts of PETN. Whether this approach is desirable depends on whether the present action time level with the MIC primers is acceptable (they meet the 3.0 msec requirement, but will have a lower rate of fire).

Primer Hardware	Shots	PETN Load [wt %]	Propellant	Mean Velocity (Std Dev) [ft/sec]	Mean Action Time (Std Dev) [msec]
#41 (reference)	10	5.0	Std M855	2767 (15)	0.906 (0.018)
#41 (MIC)	10	None	Std M855	2694 (12)	1.092 (0.042)
#41 (MIC)	10	Nominal	Std M855	2695 (13)	1.124 (0.048)
#41 (MIC)	10	Double	Std M855	2705 (14)	1.010(0.030)
PVU-1/A (MIC)	10	None	Std M855	2692 (13)	1.078 (0.009)
PVU-1/A (MIC)	5	None	Std M855$^+$	2748 (9)	1.074 (0.055)
PVU-1/A (MIC)	6	None	Fast Burn	2745 (16)	1.236 (0.131)

+ propellant charge increased by 0.4 grains

Table 20 – Effect of Various Primer and Propellant Modifications on M855 Cartridge Ballistic Performance

Navy cartridge testing with MIC primers proceeded at NSWC/IHDIV according to the test plan that appears in Table 6. All MIC primers tested were manufactured at IMP and sensitivity testing on the so-called "master batch" was completed there prior to installing them into cartridges for shipping to NSWC/IHDIV. Difficulties were encountered in installation of the primers into the empty Mk4 Mod2 cartridge cases required for flame testing, and it became necessary to produce an additional lot of primers for this purpose. Thus, all primers installed in the Mk4 Mod2 cases came from a different lot than the master batch that was used in all the other cartridges. Off-center sensitivity test results for the master batch primers are compared to PVU1/A data in Table 21. Also included in the Table is the on-center sensitivity for the Mk4 Mod2 primers in both the steel die normally used for PVU-1/A primers, and in Mk4 Mod2 cartridge cases.

Primer Lot	Offset (in)	$H_{50\%}$ (in)	Std Dev (in)	All-Fire (in-oz)	No-Fire (in-oz)
MIC	0.000	5.09	0.68	16.47	7.24
Master	0.001	6.72	1.39	26.52	7.64
Batch	0.002	7.45	1.09	25.03	10.22
(die)	0.003	10.16	1.35	32.81	14.47
Standard	0.000	4.42	0.53	13.72	6.52
PVU-1/A	0.001	5.56	0.92	19.71	7.22
(die)	0.002	7.68	1.18	26.35	10.32
	0.003	12.77	3.48	58.53	11.27
Mk4 Mod2					
die	0.000	4.64	0.32	12.11	7.76
case	0.000	4.58	0.83	16.94	5.66

ball weight = 1.94 oz

Table 21 – MIC Primer Neyer Sensitivity

The test results show that the master batch MIC primers (used in all Navy cartridge tests except the Mk4 Mod2) are slightly less sensitive than the reference PVU-1/A lot for on-center hits although both lots meet PVU-1/A specifications. The Mk4 Mod2 MIC primer lot has about the same sensitivity as the PVU-1/A lot at zero offset. For off-center hits, the MIC master batch exhibits a larger degradation in performance compared to the PVU-1/A at moderate offsets, while the PVU-1/A lot has the larger degradation at the largest offset. Small to moderate offsets are more likely to be encountered in typical weapon systems due to wear of the firing mechanism, in which case the MIC primers would be expected to be somewhat more affected than the PVU-1/A primers. The same would be true in LAT test fixtures.

Individual cartridge data for the JAU-8/A igniter tests with MIC master batch and PVU-1/A primers is listed in Table 22 along with computed mean values and standard deviations for ignition delay, peak pressure, and time to peak pressure. The mean values are plotted versus conditioning temperature in Figures 10 – 12, while pressure – time curves selected near the mean peak pressure at each temperature are presented in Figures 13 – 15. Because of the time scale, differences in ignition delay are not readily apparent. All cartridges easily met the specifications for ignition delay and peak pressure.

In general, the cartridges employing the MIC primers exhibited shorter ignition delays and quicker time to peak pressure with smaller standard deviations than those using PVU-1/A primers. Pressure – time curves exhibited similar shape for both primers, while peak pressure differed only slightly, and was not statistically significant. The MIC primed cartridges also showed less sensitivity to temperature extremes, particularly with regard to ignition delay. Thus, the MIC primers provided improved performance over the PVU-1/A primers in this particular application, although both cartridge lots met all performance specifications.

Overall performance of the M90 and M93 delay cartridges was found to be about the same with the MIC and PVU-1/A primers (Tables 23 and 24, Figures 16 – 21 and 22 – 27), respectively. The MIC primers were slightly less efficient in igniting the T-10 delay composition than were the PVU-1/A primers (they exhibited slightly longer ignition delay), although both lots met the required performance specifications. The M90 pressure – time curves show virtually identical peak pressures and variation with temperature for the two primers. The M93 shows slightly more variability than the M90, which is most likely due to variability in the longer time delay.

Two MIC primer misfires occurred in the M90 tests, one at -65°F and the other at +200°F. Firing pin indents looked normal in both incidents, and since each occurred at opposite ends of the temperature spectrum and none appeared in the M93 tests, they appear to be random, and not temperature related. A specific cause for the misfires has not been found.

The MIC primers were observed to improve performance of the CCU-51/A and CCU-61/A impulse cartridges, although the effect was more pronounced in the CCU-51/A. This is due primarily to the ease of igniting the lead azide-based output charge in the CCU-61/A, which has extremely short ignition delays. The data is presented in Tables 25 and 26 and Figures 28 – 39.

6.5 in^3 Closed Bomb +70 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-12	9.2	25.5	448	M-44	7.4	27.2	520
P-13	9.9	23.2	464	M-45	7.9	27.8	525
P-14	8.0	28.9	529	M-46	8.4	29.1	460
P-15	9.9	24.1	486	M-47	8.3	21.5	502
P-16	11.9	20.1	569	M-48	8.0	24.1	476
P-17	9.4	25.5	489	M-49	6.7	26.9	414
P-18	9.2	29.3	443	M-50	7.5	29.1	489
P-19	11.2	29.8	548	M-51	8.6	26.0	445
P-20	8.5	28.6	509	M-52	7.0	28.6	480
P-21	10.5	24.0	486	M-53	7.4	28.2	473
Mean	9.8	25.9	497	Mean	7.7	26.9	478
Std Dev	1.2	3.2	42	Std Dev	0.6	2.4	34

6.5 in^3 Closed Bomb -65 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-1	12.1	27.1	489	M-33	10.1	27.4	496
P-2	20.6	27.5	524	M-34	11.0	28.4	531
P-3	13.3	33.9	534	M-35	10.4	29.2	498
P-4	13.2	29.8	472	M-36	10.5	28.0	508
P-5	16.1	28.2	487	M-37	10.1	28.1	467
P-6	11.4	28.8	519	M-38	9.5	29.8	486
P-7	11.7	34.5	489	M-39	9.8	25.5	495
P-8	12.5	30.8	480	M-40	11.8	27.8	486
P-9	14.0	31.5	479	M-41	12.0	25.9	474
P-10	13.1	26.1	483	M-42	10.9	32.4	484
P-11	13.0	25.1	479	M-43	9.6	26.6	507
Mean	13.7	29.4	494	M-54	11.9	32.5	499
Std Dev	2.6	3.0	21	Mean	10.5	28.1	494
				Std Dev	0.8	1.9	18

6.5 in^3 Closed Bomb +200 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-22	5.0	27.0	493	M-55	5.4	28.3	518
P-23	5.2	22.9	488	M-56	5.4	26.3	489
P-24	5.7	23.5	504	M-57	7.1	27.6	504
P-25	6.4	24.9	537	M-58	6.1	22.3	491
P-26	7.4	13.8	545	M-59	7.6	15.0	509
P-27	3.9	27.1	467	M-60	5.2	26.1	489
P-28	5.8	26.1	484	M-61	5.9	23.0	498
P-29	5.1	27.0	564	M-62	7.5	20.7	549
P-30	6.0	22.8	540	M-63	6.4	22.6	515
P-31	5.7	24.4	514	M-64	6.3	20.6	489
P-32	5.8	24.8	512	M-65	6.3	23.4	524
Mean	5.6	24.0	513	Mean	6.3	23.3	507
Std Dev	0.9	3.7	30	Std Dev	0.8	3.8	19

Table 22 – JAU-8/A Igniter Performance With MIC and PVU-1/A Primers

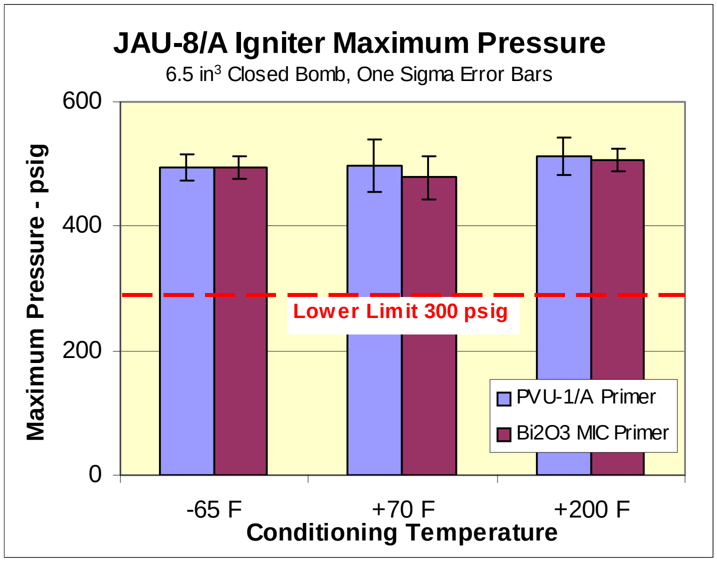


Figure 10 – JAU-8/A Igniter Peak Pressure

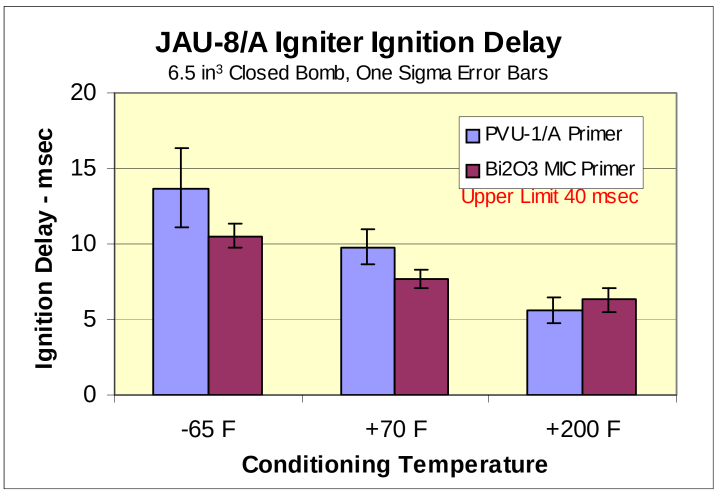


Figure 11 – JAU-8/A Igniter Ignition Delay

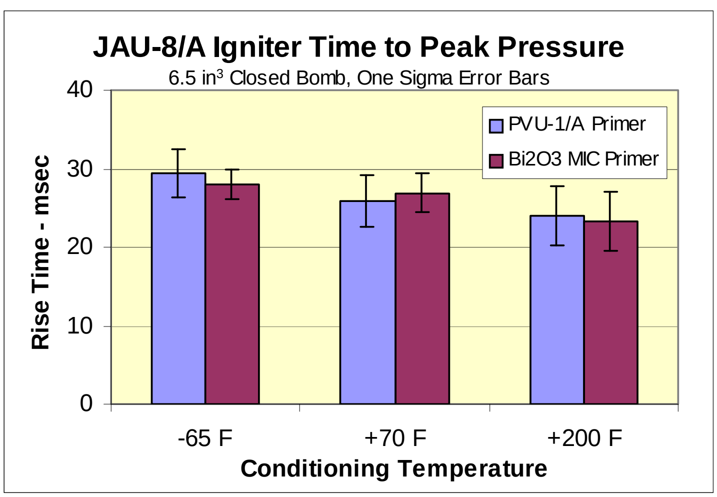


Figure 12 – JAU-8/A Igniter Time to Peak Pressure

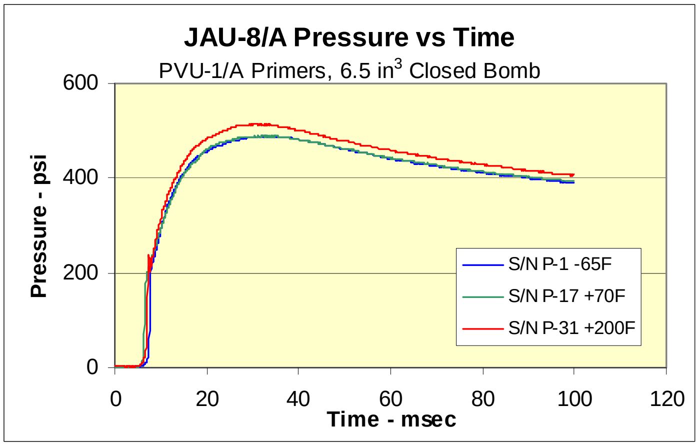


Figure 13 – Temperature Variation of JAU-8/A Igniter Pressure vs Time With PVU-1/A Primers

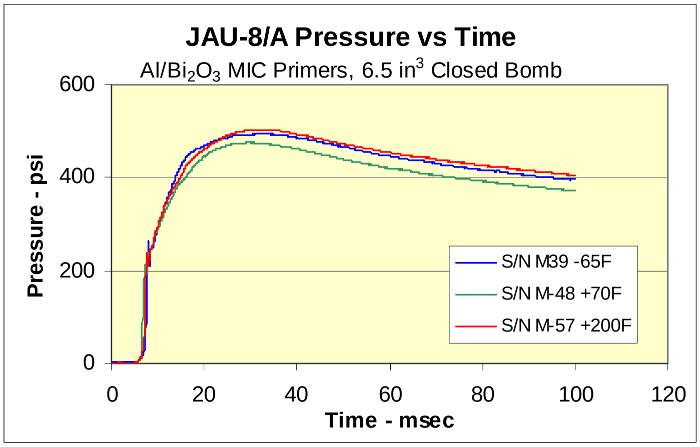


Figure 14 – Temperature Variation of JAU-8/A Igniter Pressure vs Time With MIC Primers

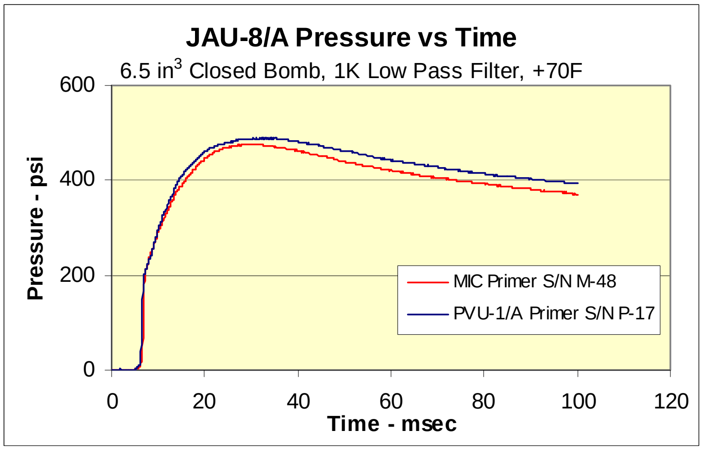


Figure 15 – JAU-8/A Igniter Pressure vs Time With MIC and PVU-1/A Primers at +70F

5.75 in^3 Closed Bomb +70 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-12	298.7	10.0	2490	M-44	314.0	9.7	2540
P-13	298.2	9.9	2480	M-45	309.0	9.7	2475
P-14	302.6	9.6	2500	M-46	304.5	10.0	2435
P-15	304.7	9.9	2530	M-47	314.3	9.7	2510
P-16	296.4	10.0	2495	M-48	305.0	9.9	2460
P-17	298.1	10.0	2485	M-49	319.1	9.7	2455
P-18	303.5	9.9	2565	M-50	318.3	10.2	2485
P-19	303.8	10.2	2515	M-51	308.6	10.3	2480
P-20	300.2	10.5	2495	M-52	308.7	9.9	2485
P-21	292.8	9.9	2480	M-53	313.1	9.9	2495
Mean	299.9	10.0	2504	Mean	311.5	9.9	2482
Std Dev	3.8	0.2	27	Std Dev	5.1	0.2	29

5.75 in^3 Closed Bomb -65 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-1	305.7	10.5	2465	M-34	324.2	11.4	2435
P-2	312.3	11.2	2465	M-35	321.8	10.8	2460
P-3	316.8	11.5	2425	M-36		Did Not Fire	
P-4	317.3	11.5	2435	M-37	327.8	11.1	2445
P-5	311.3	11.1	2455	M-38	326.7	10.6	2440
P-6	318.0	11.4	2465	M-39	341.6	11.1	2420
P-7	320.0	11.4	2450	M-40	329.9	10.8	2435
P-8	312.2	11.2	2485	M-41	333.0	12.0	2415
P-9	310.4	11.4	2450	M-42	328.1	11.1	2465
P-10	316.8	11.7	2425	M-43	319.7	11.2	2435
P-11	318.9	11.2	2420	M-54	323.1	10.9	2460
Mean	314.5	11.3	2449	Mean	327.6	11.1	2441
Std Dev	4.4	0.3	21	Std Dev	6.3	0.4	17

5.75 in^3 Closed Bomb +200 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-22	291.5	9.1	2540	M-55	300.3	9.0	2545
P-23	284.1	8.7	2520	M-56	293.9	8.5	2525
P-24	288.2	8.7	2545	M-57	291.5	8.7	2525
P-25	291.2	9.0	2510	M-58	291.3	8.4	2540
P-26	285.8	8.4	2550	M-59		Did Not Fire	
P-27	292.5	8.7	2535	M-60	307.7	9.1	2500
P-28	284.6	8.5	2550	M-61	292.8	9.0	2535
P-29	269.6	8.8	2520	M-62	289.2	8.7	2520
P-30	293.9	9.4	2520	M-63	287.7	8.7	2520
P-31	282.6	8.5	2535	M-64	288.6	8.5	2560
P-32	288.5	9.1	2530	M-65	297.0	8.7	2565
Mean	286.6	8.8	2532	Mean	294.0	8.7	2534
Std Dev	6.7	0.3	13	Std Dev	6.2	0.2	20

Table 23 – M90 Delay Cartridge Performance With MIC and PVU-1/A Primers

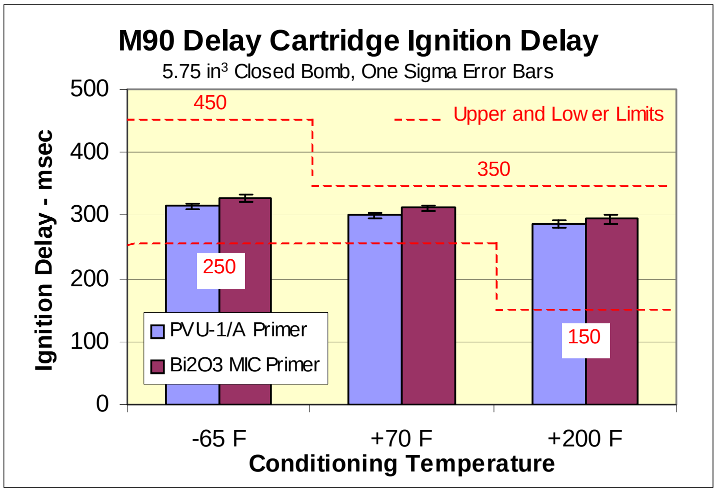


Figure 16 – M90 Delay Cartridge Ignition Delay

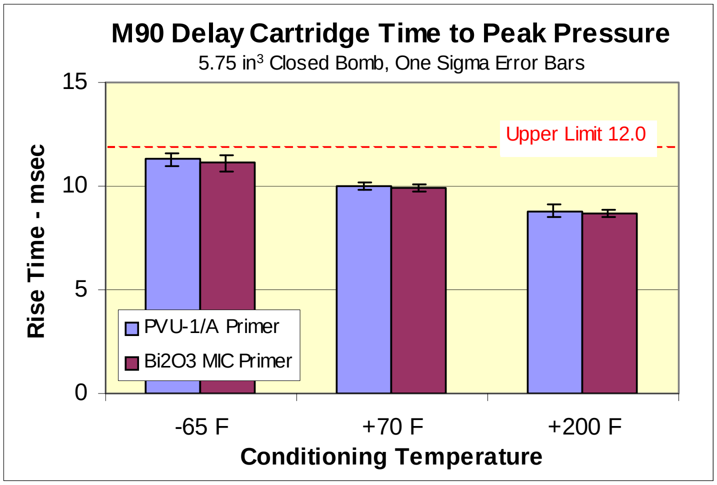


Figure 17 – M90 Delay Cartridge Time to Peak Pressure

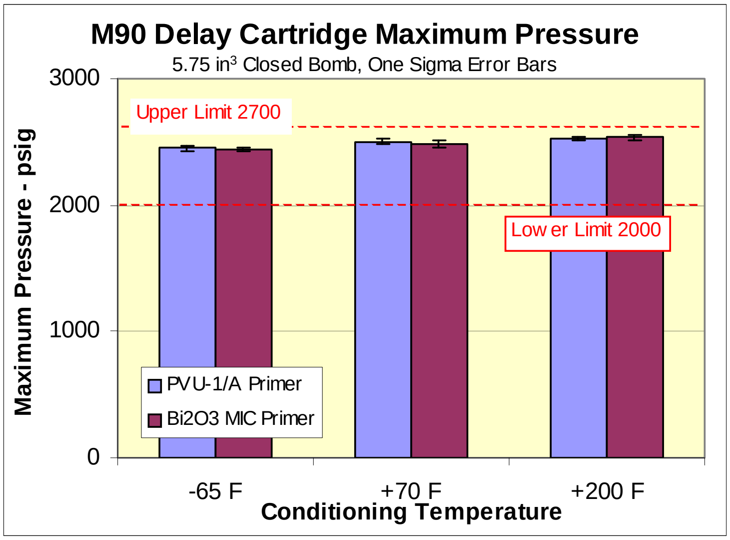


Figure 18 – M90 Delay Cartridge Peak Pressure

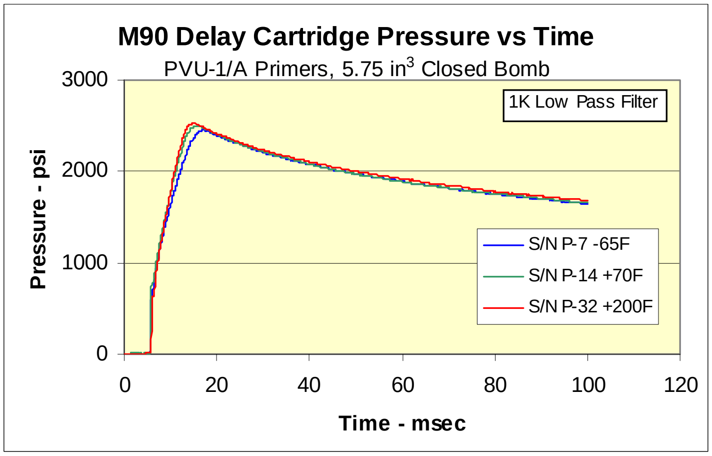


Figure 19 – Temperature Variation of M90 Delay Cartridge Pressure vs Time With PVU-1/A Primers

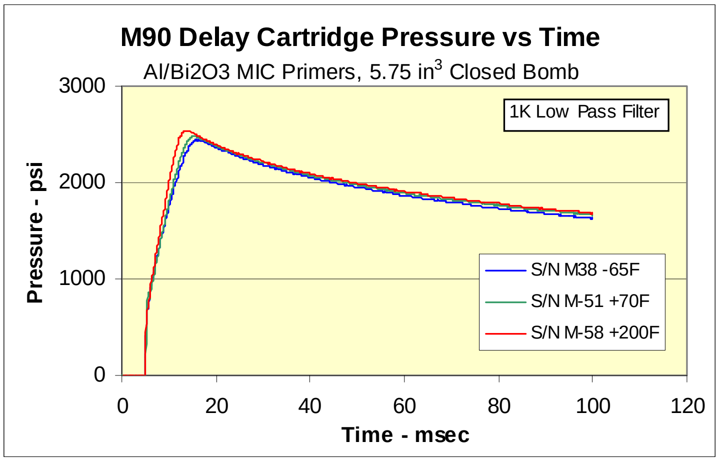


Figure 20 – Temperature Variation of M90 Delay Cartridge Pressure vs Time With MIC Primers

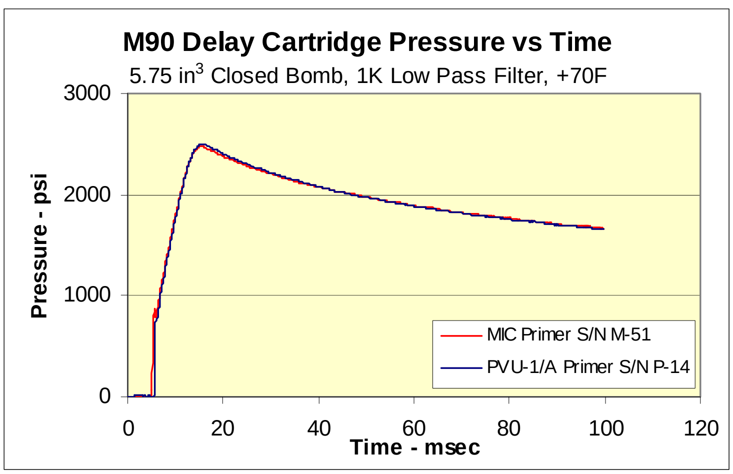


Figure 21 – M90 Delay Cartridge Pressure vs Time With MIC and PVU-1/A Primers at +70F

5.75 in^3 Closed Bomb				+70 F			
PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-11	1062.2	39.0	2910	M-44	1073.0	32.6	3010
P-12	1039.4	37.8	2980	M-45	1106.0	40.0	3005
P-13	1060.6	39.6	2955	M-46	1064.6	39.6	2975
P-14	1055.8	37.8	2940	M-47	1110.4	38.0	2930
P-15	1053.2	40.2	2900	M-48	1080.8	40.6	2865
P-16	1054.2	41.8	2975	M-49	1077.0	40.6	2910
P-17	1055.6	39.4	3055	M-50	1066.2	36.4	2990
P-18	1030.2	38.2	2940	M-51	1095.4	37.6	3045
P-19	1033.2	38.0	3035	M-52	Did Not Fire		
P-20	1059.0	35.8	2940	M-53	1087.6	40.2	2980
P-21	1043.4	38.6	3035	M-65	1109.6	40.4	2980
Mean	1049.7	38.7	2970	Mean	1084.6	38.4	2968
Std Dev	11.2	1.5	52	Std Dev	16.6	2.6	56

5.75 in^3 Closed Bomb				-65 F			
PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-1	1109.9	36.5	2940	M-33	1133.4	40.0	2910
P-2	1082.6	37.9	2940	M-34	1131.0	37.4	2935
P-3	1099.7	42.4	2950	M-35	1083.2	37.0	2915.0
P-4	1070.6	41.8	2875	M-36	1177.6	42.0	2900
P-5	1084.2	40.2	2910	M-37	Did Not Fire		
P-6	1082.6	41.2	2965	M-38	1113.2	39.4	2935
P-7	1083.6	41.2	2905	M-39	1127.8	42.8	2850
P-8	1119.2	41.4	2960	M-40	1104.4	37.8	2945
P-9	1094.6	46.0	2870	M-41	1137.8	38.8	2975
P-10	1090.6	41.2	2905	M-42	1154.6	42.0	2935
				M-43	1087.8	39.0	2985
Mean	1091.8	41.0	2922	Mean	1125.1	39.6	2929
Std Dev	14.5	2.5	34	Std Dev	29.1	2.0	38

5.75 in^3 Closed Bomb				+200 F			
PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Pressure Rise Time (msec)	Pmax (psi)
P-22	1048.0	33.8	2960	M-54	1117.2	36.8	3015
P-23	1057.8	32.0	3100	M-55	1095.6	36.8	3030
P-24	1029.2	37.0	3020	M-56	1035.6	35.6	3055
P-25	1042.2	37.0	3025	M-57	1022.0	34.8	3000
P-26	1047.0	36.6	3070	M-58	1049.8	36.6	3090.0
P-27	1035.6	35.8	3045	M-59	1065.6	36.6	3005
P-28	1009.6	35.6	3020	M-60	1027.4	35.2	3105
P-29	1051.2	33.0	3010	M-61	1050.4	36.4	3040
P-30	1056.0	37.0	3000	M-62	1034.6	33.4	3065
P-31	1042.4	29.2	2965	M-63	1071.4	34.6	2970
P-32	1043.0	35.2	3010	M-64	1036.4	36.2	3060
Mean	1042.0	34.7	3020	Mean	1055.1	35.7	3040
Std Dev	13.6	2.5	41	Std Dev	29.9	1.1	41

Table 24 – M93 Delay Cartridge Performance With MIC and PVU-1/A Primers

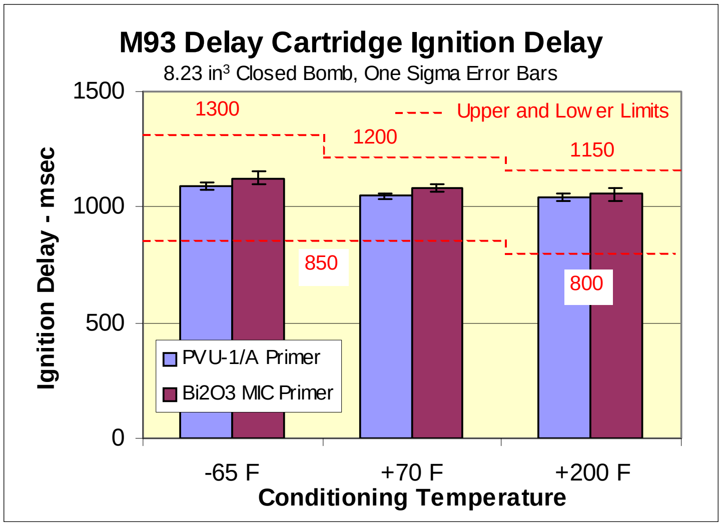


Figure 22 – M93 Ignition Delay

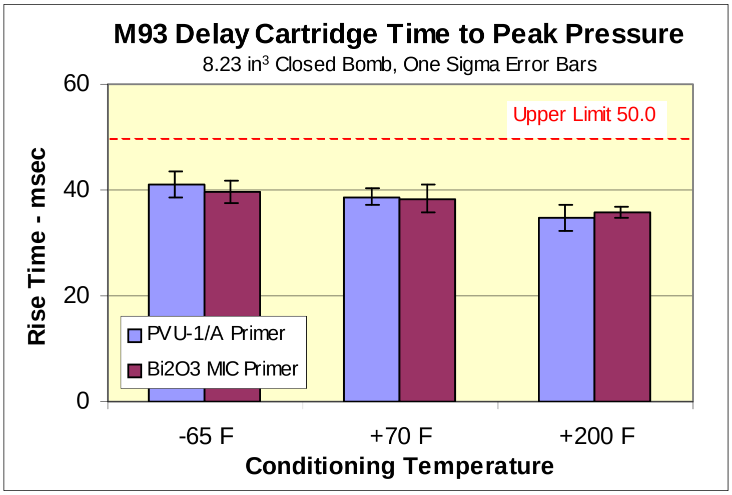


Figure 23 – M93 Time to Peak Pressure

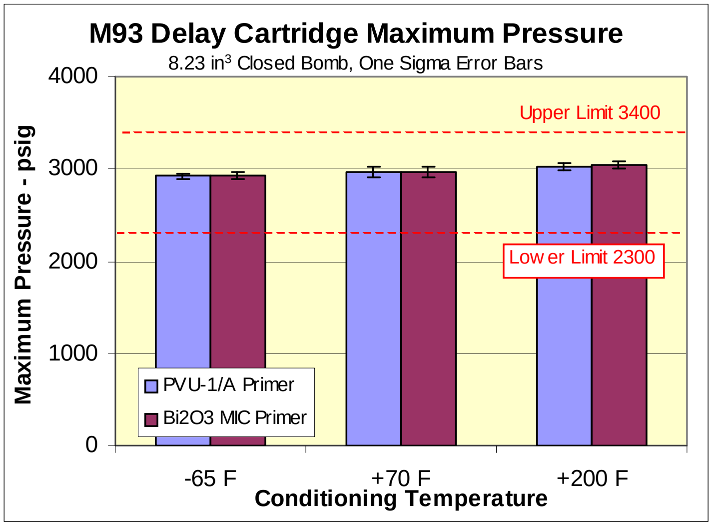


Figure 24 – M93 Peak Pressure

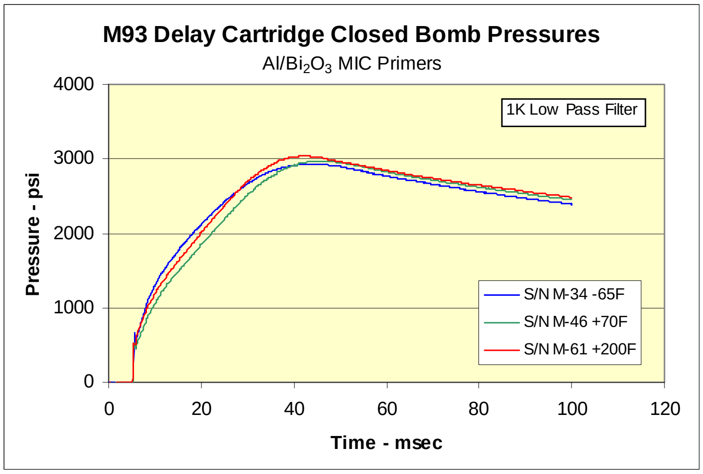


Figure 25 – Temperature Variation of M93 Delay Cartridge Pressure vs Time With PVU-1/A Primers

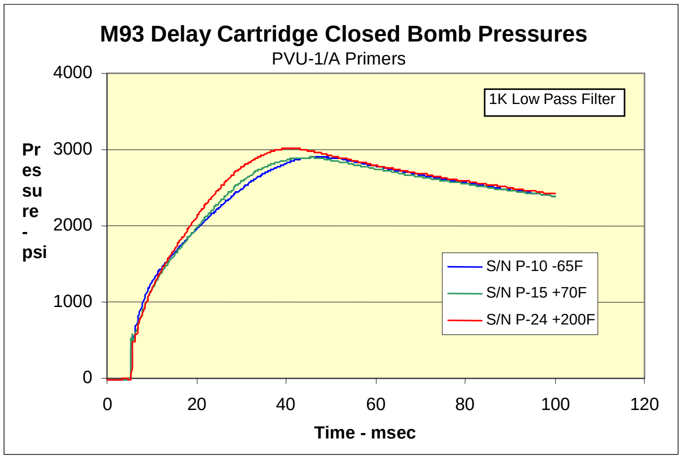


Figure 26 – Temperature Variation of M93 Delay Cartridge Pressure vs Time With MIC Primers

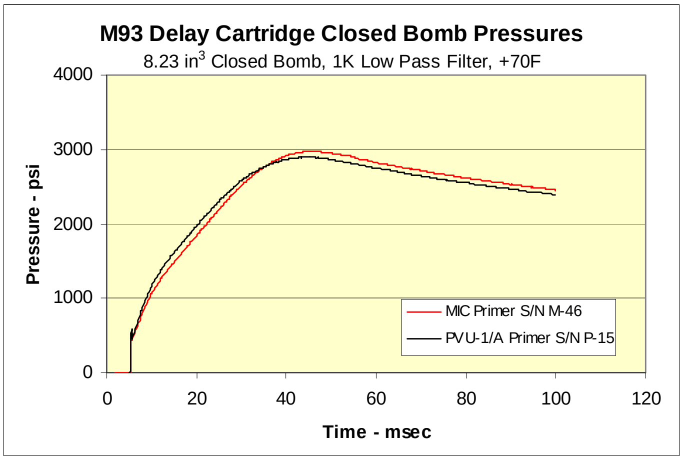


Figure 27 – M93 Delay Cartridge Pressure vs Time With MIC and PVU-1/A Primers at +70F

5.0 in^3 Closed Bomb +70 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)
Spec	50.0 max	50.0 max	950-1350	Spec	50.0 max	50.0 max	950-1350
P-5	15.8	44.9	944	M-44	6.3	25.6	992
P-6	12.6	42.7	978	M-45	6.1	35.7	996
P-7	14.6	45.0	988	M-46	5.6	31.4	1082
P-8	14.6	49.9	980	M-47	5.3	32.2	1056
P-20	12.4	35.1	1026	M-48	4.9	23.2	1026
P-21	10.7	37.6	920	M-49	5.5	34.3	1016
P-22	10.5	34.2	1030	M-50	6.4	35.2	992
P-23	9.5	34.3	956	M-51	7.6	36.1	1030
P-24	14.1	48.1	986	M-52	4.7	25.7	998
P-25	6.3	34.5	1006	M-53	5.0	26.1	1038
Mean	12.1	40.6	981	M-54	5.3	17.5	1078
Std Dev	2.9	6.2	35	Mean	5.7	29.4	1028
				Std Dev	0.8	6.1	33

5.0 in^3 Closed Bomb -65 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)
Spec	50.0 max	50.0 max	950-1350	Spec	50.0 max	50.0 max	950-1350
P-1	18.4	45.3	1018	M-33	4.6	16.9	1048
P-2	11.3	35.6	1004	M-34	4.4	24.6	894
P-3	17.2	39.2	920	M-35	6.2	13.0	960
P-4	14.6	39.7	946	M-36	5.6	28.0	942
P-13	12.0	44.7	940	M-37	7.6	14.1	960
P-14	16.0	42.1	934	M-38	5.5	14.5	974
P-15	11.5	40.7	970	M-39	7.0	29.8	922
P-16	8.7	38.3	944	M-40	6.2	24.7	892
P-17	10.9	39.4	904	M-41	6.5	19.2	986
P-18	11.4	42.6	986	M-42	5.2	25.8	956
P-19	14.2	39.5	950	M-43	6.1	16.5	1026
Mean	13.3	40.6	956	M-66	6.1	14.8	1044
Std Dev	3.0	2.8	35	M-67	5.0	10.6	1058
				M-68	6.8	20.2	1024
				M-69	6.4	18.4	1080
				M-70	5.1	8.4	1052
			with disc	Mean	5.9	20.6	960
				Std Dev	1.0	6.1	49
			without disc	Mean	5.9	14.5	1052
				Std Dev	0.8	5.0	20

5.0 in^3 Closed Bomb +200 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)
Spec	50.0 max	50.0 max	950-1350	Spec	50.0 max	50.0 max	950-1350
P-9	13.2	34.6	984	M-55	4.0	17.0	1038
P-10	11.7	37.0	984	M-56	6.3	23.7	988
P-11	13.4	31.3	990	M-57	4.9	22.7	1056
P-12	15.3	38.2	1016	M-58	5.4	16.1	1040
P-26	9.4	36.3	1006	M-59	4.7	24.0	988
P-27	8.6	38.1	992	M-60	5.5	24.1	1020
P-28	8.2	36.0	1026	M-61	5.6	29.9	1026
P-29	10.6	38.8	1052	M-62	6.1	29.1	948
P-30	13.4	36.6	1022	M-63	5.3	19.5	1024
P-31	6.8	33.7	1108	M-64	5.0	13.9	1034
P-32	8.9	37.8	970	M-65	5.2	26.9	1112
Mean	10.9	36.2	1014	M-71	4.7	13.6	1088
Std Dev	2.7	2.2	39	M-72	5.8	17.8	1106
				M-73	5.2	17.9	1034
				M-74	4.9	24.2	1076
				M-75	5.5	19.2	1066
			with disc	Mean	5.3	22.4	1025
				Std Dev	0.6	5.3	42
			without disc	Mean	5.2	18.5	1074
				Std Dev	0.4	3.8	27

Table 25 – CCU-51/A Impulse Cartridge Performance With MIC and PVU-1/A Primers

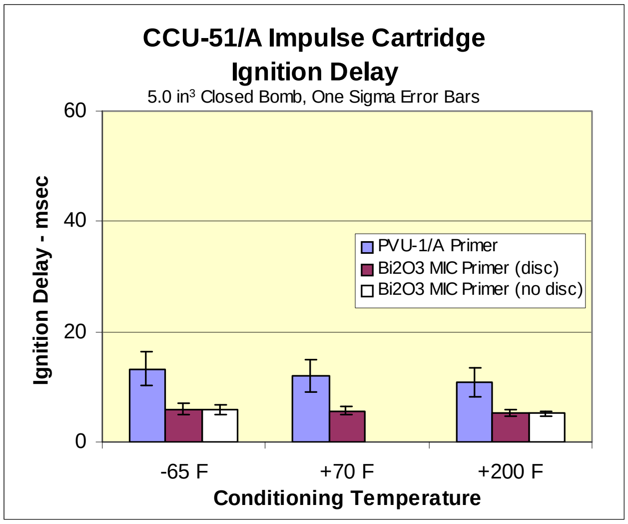


Figure 28 – CCU-51/A Impulse Cartridge Ignition Delay

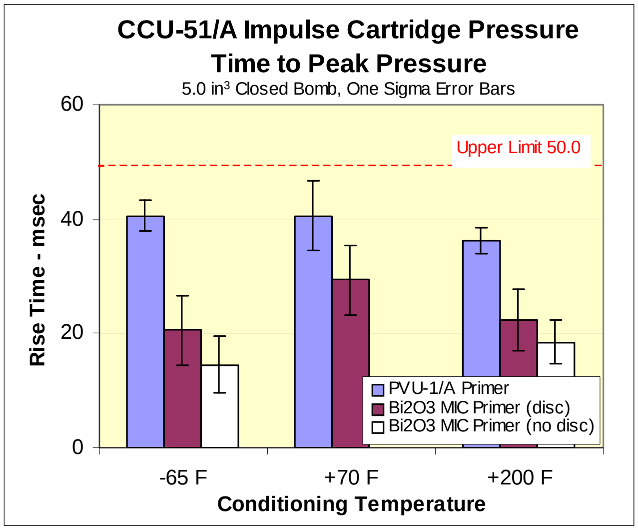


Figure 29 – CCU-51/A Impulse Cartridge Time to Peak Pressure

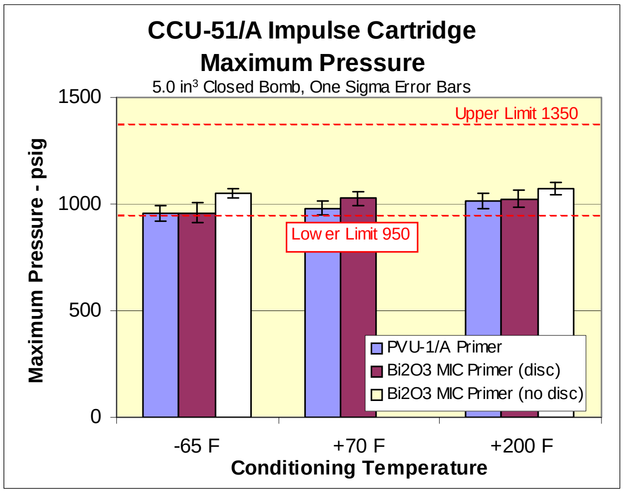


Figure 30 – CCU-51/A Impulse Cartridge Peak Pressure

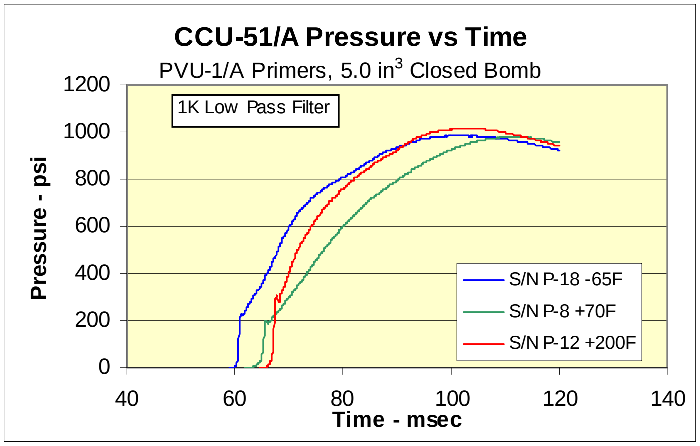


Figure 31 – Temperature Variation of CCU-51/A Impulse Cartridge Pressure vs Time With PVU-1/A Primers

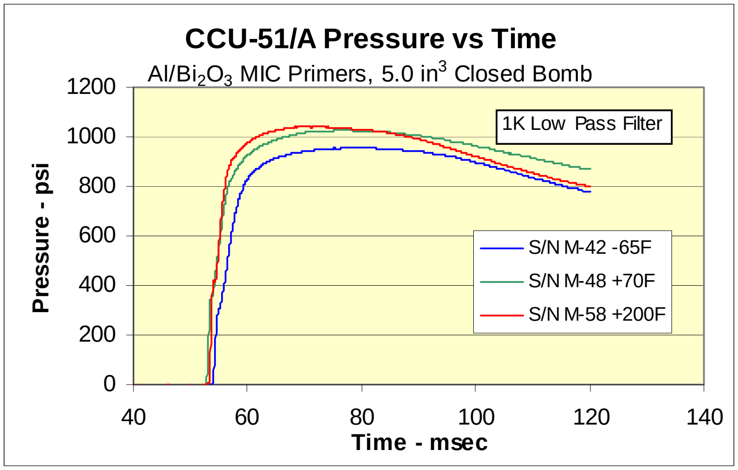


Figure 32 – Temperature Variation Of CCU-51/A Impulse Cartridge Pressure vs Time With MIC Primers

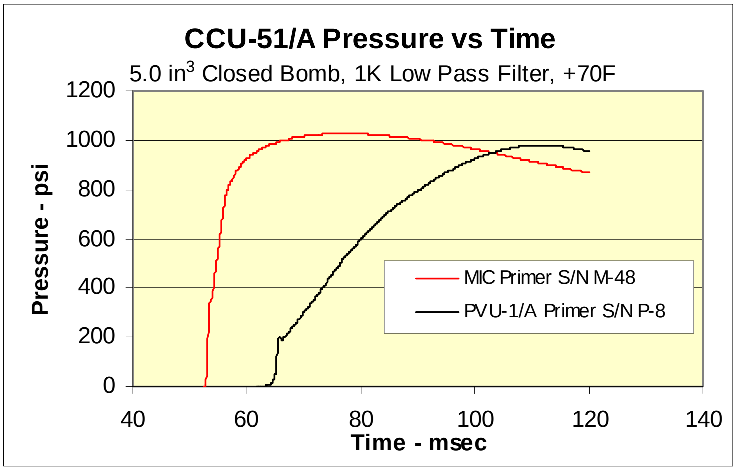


Figure 33 – CCU-51/A Impulse Cartridge Pressure vs Time With MIC and PVU-1/A Primers at +70F

10.0 cc Closed Bomb +70 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)
Spec	50.0 max	none	450-900	Spec	50.0 max	none	450-900
P-12	2.7	0.7	652	M-44	2.2	0.6	844
P-13	2.1	0.6	1010	M-45	2.0	0.7	1034
P-14	2.2	0.7	1008	M-46	1.8	0.7	918
P-15	2.5	0.7	704	M-47	2.1	0.7	848
P-16	2.3	0.7	696	M-48	2.0	0.6	912
P-17	2.0	0.7	616	M-49	2.3	0.6	872
P-18	2.4	0.6	816	M-50	2.0	0.7	816
P-19	2.3	0.7	552	M-51	1.9	0.8	852
P-20	2.3	0.7	742	M-52	2.0	0.6	862
P-21	2.3	0.7	582	M-53	1.7	0.7	876
P-32	2.3	0.8	570	Mean	2.0	0.7	883
Mean	2.3	0.7	723	Std Dev	0.2	0.1	61
Std Dev	0.2	0.1	162				

10.0 cc Closed Bomb -65 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)
Spec	50.0 max	none	450-900	Spec	50.0 max	none	450-900
P-1	2.8	0.6	736	M-33	2.4	0.7	890
P-2		No Data		M-34	1.8	0.6	900
P-3	2.4	0.8	688	M-35	2.4	0.6	892
P-4	2.3	0.7	564	M-36	2.2	0.7	918
P-5	3.1	0.7	542	M-37	2.4	0.7	978
P-6	2.2	0.7	676	M-38	2.3	0.6	900
P-7	2.0	1.3	614	M-39	2.1	0.6	872
P-8	2.2	0.7	636	M-40	2.0	0.6	918
P-9	2.3	0.7	594	M-41	2.4	0.7	852
P-10	1.9	0.7	946	M-42	2.0	0.6	876
P-11	2.5	0.8	600	M-43	2.2	0.6	878
Mean	2.4	0.8	660	Mean	2.2	0.6	898
Std Dev	0.4	0.2	117	Std Dev	0.2	0.1	33

10.0 cc Closed Bomb +200 F

PVU-1/A Primer				Al/Bi_2O_3 MIC Primer			
S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)	S/N	Ignition Delay (msec)	Time to Pmax (msec)	Pmax (psi)
Spec	50.0 max	none	450-900	Spec	50.0 max	none	450-900
P-22	2.1	0.6	898	M-54	1.9	0.6	860
P-23	2.7	0.7	1008	M-55	1.9	0.6	900
P-24	2.5	0.8	580	M-56	2.2	0.7	884
P-25	2.4	0.7	572	M-57	2.8	0.6	908
P-26	2.0	0.8	574	M-58	2.7	0.6	868
P-27	1.9	0.7	738	M-59	1.8	0.6	944
P-28	1.9	0.7	958	M-60	1.9	0.6	904
P-29	1.8	0.8	758	M-61	1.8	0.6	908
P-30	2.3	0.7	886	M-62	1.8	0.6	890
P-31	2.0	0.6	866	M-63	1.9	0.6	884
Mean	2.2	0.7	784	M-64	1.9	0.7	870
Std Dev	0.3	0.1	165	M-65	1.8	0.7	856
				Mean	2.0	0.6	890
				Std Dev	0.4	0.05	25

Table 26 – CCU-61/A Impulse Cartridge Performance With MIC and PVU-1/A Primers

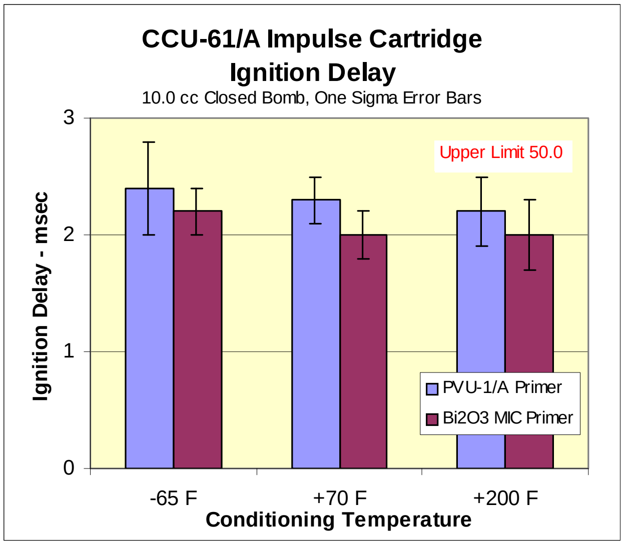


Figure 34 – CCU-61/A Ignition Delay

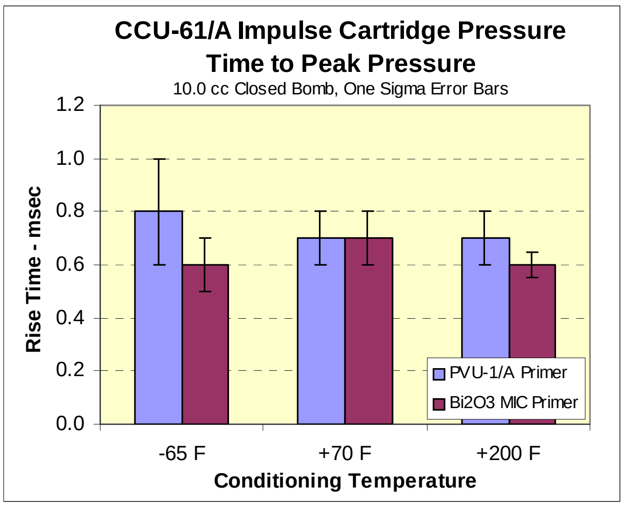


Figure 35 – CCU-61/A Time to Peak Pressure

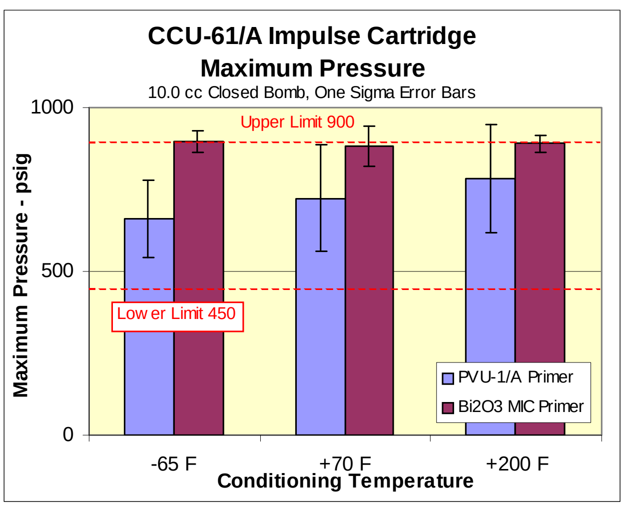


Figure 36 – CCU-61/A Peak Pressure

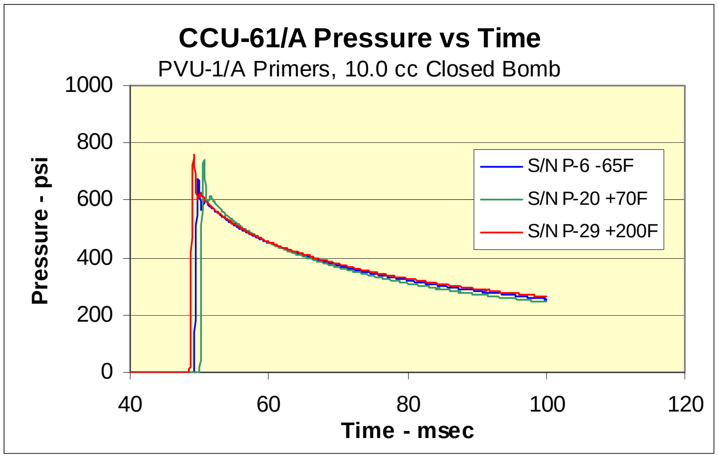


Figure 37 – Temperature Variation of CCU-61/A Impulse Cartridge Pressure vs Time With PVU-1/A Primers

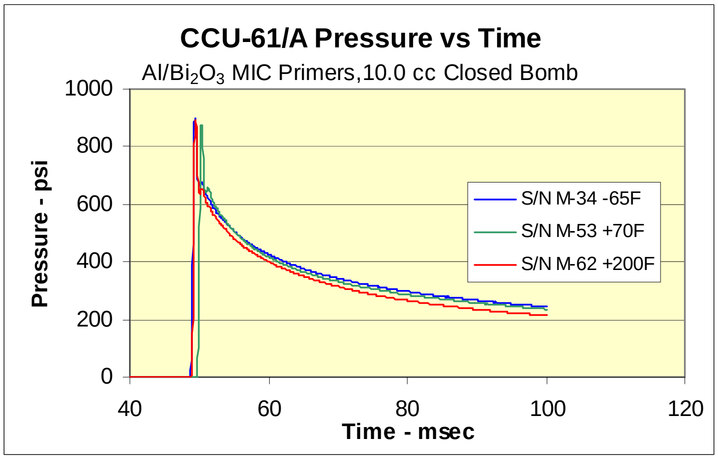


Figure 38 – Temperature Variation of CCU-61/A Impulse Cartridge Pressure vs Time With MIC Primers

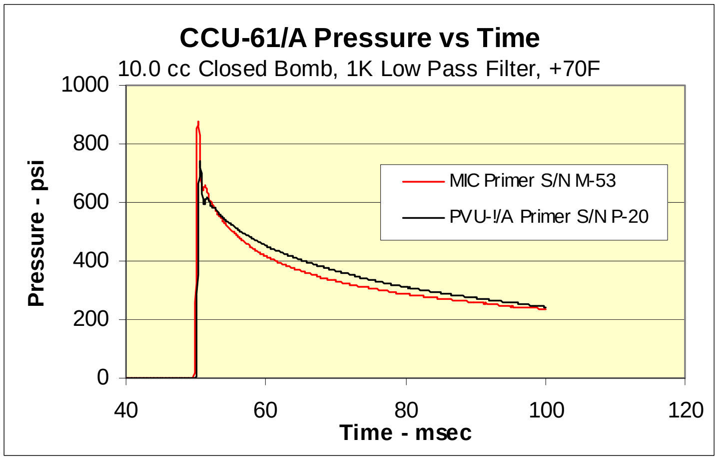


Figure 39 – CCU-61/A Impulse Cartridge Pressure vs Time With MIC and PVU-1/A Primers at +70F

As was mentioned in Section 3.6.6, most of the CCU-51/A cartridges manufactured with MIC primers contained a thin aluminum disc that covered the output end of the primer spithole. The disc was installed to prevent possible primer dust from falling into the output charge. This modification is not part of the official CCU-51/A drawing package and was not incorporated into the cartridges manufactured with standard PVU-1/A primers. An additional 10 MIC-primed cartridges were made without the disc to allow investigation its effectiveness. Due to the small number available, they were fired only at the temperature extremes (5 each).

The closed bomb data (Table 25, Figures 27 – 32) show a significant improvement in cartridge performance with the MIC primers, namely much shorter ignition delays and time to peak pressure, and higher peak pressure. Ignition delays are far below the upper limit of 50 msec with both primers. Many of the cartridges (both PVU-1/A-primed and MIC-primed) were below the lower limit on peak pressure. This appears to be the result of low output charge weight rather than poor ignition of the output charge. In normal cartridge manufacturing procedures trial shots would be made to adjust the output charge to the middle of the pressure range specification. This was not done here, as it was not necessary to meet the specification. Both the PVU-1/A-primed and MIC-primed cartridges contained the same output charge, thereby ensuring a valid comparison of their respective performance.

The pressure-time curves presented in Figures 31 – 33 represent typical performance near the mean peak pressure for each of the two primer lots. These show a dramatic steepening of the curves with the MIC primer, indicating superior ignition of the output charge. Regarding the aluminum disc, its presence appears to be counterproductive – although ignition delays did not seem to be affected, both time to peak pressure and peak pressure increased without it, suggesting that the disc was metering flow through the primer spithole.

The closed bomb results obtained with the CCU-61/A impulse cartridges (Table 26, Figures 33 – 38) also showed performance improvements with the MIC primers. Ignition delay and time to peak pressure showed modest reductions and a little less temperature sensitivity in what are already very low values. At cold temperatures the corresponding MIC primer standard deviations showed some improvement, but were about the same as those with the PVU-1/A primers at ambient and hot temperatures. Peak pressures increased significantly with the MIC primers, however, and were remarkably constant across the temperature extremes. Furthermore, with the MIC primers standard deviations in peak pressure were 62 to 85 percent lower than those with the PVU-1/A primers, indicating far better ignition of the output charge. In fact, the improved ignition pushed ten of the MIC-primed cartridges over the high pressure limit, whereas, only two of the PVU-1/A-primed cartridges exceeded it. The pressure – time curves clearly show the increase in the peak values obtained with the MIC primers.

The sequence of flame tests conducted in empty Mk4 Mod2 cartridges is presented in Table 27. All tests were conducted in a darkened room in front of a grid of 2 x 2 inch squares. A small red light that was illuminated by the current applied to the firing solenoid was placed next to the mouth of the cartridges to provide a timing mark in the high speed video images obtained.

-65F

Rnd No.	S/N	Frame Rate	Flame Length (in)	Flame Width (in)
1	P-125	2K	3.8	0.8
2	P-121	4K	None Visible	
3	P-126	4K	None Visible	
4	M-536	4K	7.8	2.3
5	P-123	2K	2.7	2.4
6	P-124	2K	3.1	0.8
7	P-127	2K	2.0	1.1
8	P-122	2K	2.2	0.4
9	P-147	2K	3.0	1.4
10	P-145	2K	1.1	0.4
11	M-540	2K	8.4	2.4
12	M-537	2K	8.5	2.5
13	M-539	2K	8.3	2.3
14	M-538	2K	8.2	2.5
15	M-535	2K	7.9	2.3
16	M-541	2K	8.1	2.8
17	M-557	2K	8.2	2.6
18	M-561	2K	8.4	2.3

+200F

Rnd No.	S/N	Frame Rate	Flame Length (in)	Flame Width (in)
1	P-141	2K	None Visible	
2	P-136	2K	None Visible	
3	M-552	2K	No-Fire	
4	M-551	2K	No-Fire	
5	M-549	2K	8.6	2.5
6	M-555	2K	7.7	2.5
7	M-553	2K	No-Fire	
8	M-554	2K	No-Fire	
9	P-138	2K	1.2	0.8
10	P-137	2K	None Visible	
11	P-140	1K	0.1	0.1
12	P-139	1K	2.6	1.1
13	P-135	1K	2.2	0.9
14	P-142	1K	2.3	0.9
15	P-143	1K	4.0	0.8
16	M-550	1K	No-Fire	
17	M-564	1K	No-Fire	
18	M-560	1K	No-Fire	

+70F

Rnd No.	S/N	Frame Rate	Flame Length (in)	Flame Width (in)
1	P-128	1K	None Visible	
2	P-131	1K	No-Fire*	
3	P-129	1K	2.3	0.5
4	P-134	1K	1.7	0.4
5	M-543	1K	8.7	2.7
6	M-548	1K	8.1	2.9
7	M-545	1K	9.0	2.8
8	M-547	1K	8.9	2.9
9	M-546	1K	8.8	2.5
10	M-544	1K	8.1	3.0
11	M-542	1K	9.3	2.5
12	M-559	1K	9.0	2.9
13	M-562	1K	8.7	2.7
14	P-130	1K	2.8	0.4
15	P-132	1K	3.2	0.7
16	P-133	1K	None Visible	
17	P-150	1K	0.6	0.3
18	P-144	1K	0.5	0.2

* light hit on primer, spring replaced

Table 27 – MIC and PVU-1/A Primer Flame Tests in Mk4 Mod2 Cartridge Cases

The framing rate of the high-speed video camera was varied during the tests in an attempt to obtain optimum definition of the flame produced by the primers. The 1000 fps framing rate was found to provide the best results. In general it was found that the "flame" from both primers persisted for only about 4.0 msec, although in some of the PVU-1/A tests a visible flame could not be detected. Figure 39 shows a 4.0 msec long continuous sequence for a MIC and PVU-1/A primer. The visible light from the MIC primer clearly illuminates the grid behind it, while the grid is barely visible in the light generated by the PVU-1/A primer. The red timing light appears at the right center of each frame, and in some of the PVU-1/A tests, was the only light visible in the entire sequence. Streams of hot particles (which may actually be liquid) are also visible, and persist for about 4.0 msec. It is difficult to tell whether what appears to be a luminous "flame" is actual hot gases or just blooming of the image of the hot particles (the camera iris was wide open at f/2.8 for all tests). Since both primers are known to produce pressure, the luminosity is probably a combination of both. In any event, the spatial extent of the hot combustion products from the MIC primer is consistently about three times that of the PVU-1/A in both length and width, suggesting significantly higher pressure and temperature with the MIC. This would be expected to increase the ignition efficiency of the MIC primer with output charges containing constituents with pressure sensitive burning rates (double base propellants found in impulse cartridges and small arms ammunition, for example), but not delay cartridges. This is, of course, exactly what has been observed it the present tests.

Several misfires were experienced with MIC primers at +200°F. These started immediately after two successful PVU-1/A shots when firing commenced the day after a full 18 shot sequence had been fired at -65°F. Alternating the firing sequence between MIC and PVU-1/A primers showed that it was only the MIC primers that were misfiring. Inspection of the firing pin indents in the misfired primers showed no evidence of light hits. When firing the +70°F shots the next day, the second PVU-1/A misfired, and a very obvious light hit was observed on the firing pin strike. At this point, the spring in the firing mechanism was changed, and all remaining MIC and PVU-1/A primers fired satisfactorily. From these events, it was concluded that although a new spring had been installed in the firing mechanism prior to starting the -65°F shots, it had been degrading throughout the duration of the tests, which was unusually long for this particular test fixture. Normally only a few shots are fired during one test in this fixture, just enough to get some good pictures, and only at ambient temperature. A new spring is always installed prior to starting a new test, meaning that the springs had never before been exposed to the usage levels of the present tests. Evidently the spring needs replacing more frequently than had been realized.

It is noteworthy that the MIC primers seemed to be more sensitive to spring energy than the PVU-1/A primers. The MIC primers used in the flame tests came from a different lot than all the others employed in the test program, and while it is possible that some slight variability in manufacturing technique may have something to do with the misfires, the ball drop sensitivity tests with the flame test lot show nothing unusual. Another interesting possibility results from the fact that the MIC primers have very tight standard deviations. This results in narrow limits between all-fire and no-fire energies, which may need some adjusting to reduce sensitivity to moderately worn firing mechanisms. This could be easily accomplished by a small change in the particle size of the MIC composition.

MIC Primer S/N M-542 PVU-1/A Primer S/N P-132

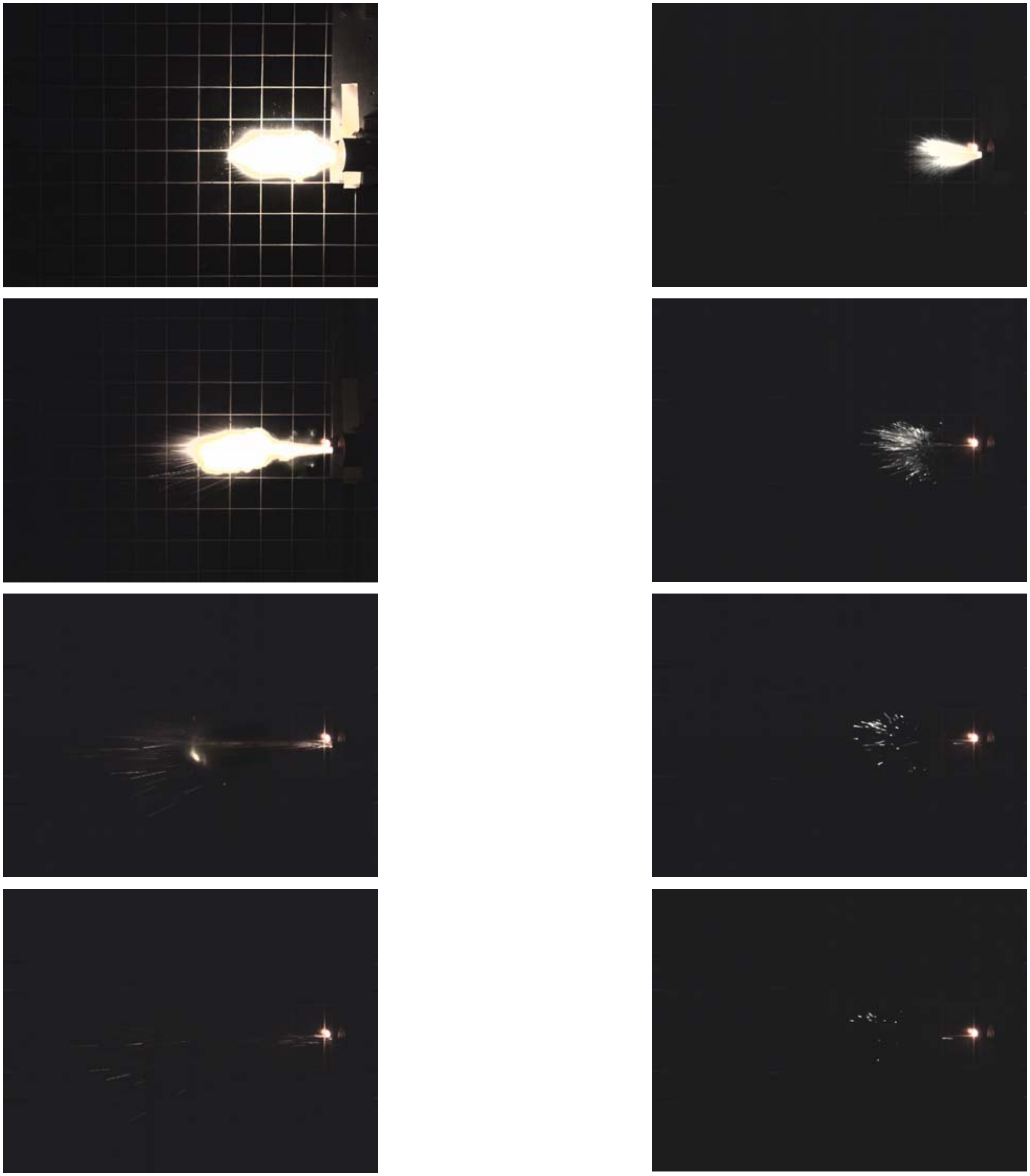


Figure 40 – Continuous Four Frame Sequence of MIC and PVU-1/A Primer Flame Tests
Framing Rate: 1000 frames/second

In summary, the demonstration test has shown that with one exception the Al/Bi_2O_3 MIC primer has ignition performance that is either better or equal to that for existing lead styphnate-based primer compositions. The one exception is slightly longer action time in M855 cartridge tests, which results in slightly lower rates of fire in burst mode. The MIC primer easily meets the 3-sigma requirement, however. Thus, the MIC primer as it now exists meets the objective of a drop-in, lead-free replacement for the primers currently found in DoD small arms ammunition and cartridge actuated devices. The demonstration, therefore, has been entirely successful. This does not mean that the MIC primer is ready for qualification, as two major issues with it must still be resolved.

The most difficult issue is whether a common primer formulation can be found for both Army and Navy applications, which have quite different performance specifications. The supplemental small arms testing reported here-in indicates that addition of moderate amounts of PETN to the MIC composition does not reduce action time. Additional testing (presumably in the ATF) must be done to confirm this result, as elimination of PETN in the M855 primers would result in a common MIC formulation for both Army and Navy applications. If action times comparable to the #41 primer are desired, however, more work on the formulation would be required. A reduction of about 20% would be needed.

The second issue is misfires. While none are desired, the small number experienced in this extensive test program is not particularly worrisome. The majority of the misfires appears to be a Mk4 Mod2 test fixture problem, and an investigation into this possibility is in progress. All misfire cartridges, including the M90 and M93 delay cartridges, have been retained and will be thoroughly examined as part of this investigation. The major operational objective of the test program has been to demonstrate that the MIC primers work at least as well as those they are intended to replace, and without question, this has been accomplished. The MIC primer composition used to date has not yet been fully optimized, and it is expected that further effort in this direction will result in elimination of misfires.

DOD qualification procedures for the introduction of new pyrotechnic materials into use in the US Armed Forces are specified in NAVSEAINST 8020.5C [8]. The procedures outlined in this document are those which must be followed by both the US Army and US Navy to qualify the Al/Bi_2O_3 MIC composition for use in lead-free replacements for the No. 41 and PVU-1/A primers. For pyrotechnic compositions, there are nine tests that are mandated:

- Impact Sensitivity
- CAP Test
- Thermal Stability
- Vacuum Stability
- Self Heating
- Friction Sensitivity
- Electrostatic Sensitivity
- Aging Characteristics
- Toxicity

These nine tests fall into three broad categories - performance, safety, and thermal stability. In most cases, all but one, aging characteristics, are performed during design and development of the composition. The aging test has a one year duration wherein the primer composition is stored at 70°C in unsealed containers. DTA testing is performed prior to the start of the test to obtain baseline data, and then, after six months and twelve months of aging have been completed, samples are withdrawn and the DTA test is repeated. To pass the test, there must be no significant difference between the baseline data and the data obtained with the aged composition. The primer qualification, which is a separate process, then proceeds according to the weapon specification for that particular item. Primers cannot be qualified with an unqualified primer composition.

5. Cost Assessment

5.1 Cost Reporting

Because MIC primer manufacturing at IMP is primarily a series of hand operations, the operational costs for manufacturing Bi_2O_3 MIC primers there are dominated by labor costs. The same is true for current PVU-1/A production at NSWC/IHDIV, which is normally done in small batches. Table 28 lists the cost of producing a lot of 500 MIC primers at IMP. Case A represents the actual costs of producing the primers used in the demonstration and includes storage costs (one hour of labor) but not capital equipment costs, which were about $10,000. Case B shows projected costs with a reduced labor rate corresponding to a continuously running mixing and loading operation. Case C shows projected costs to produce a 500 primer lot at NSWC/IHDIV, where the hourly labor rate is considerably higher than those used in Cases A and B. The actual costs to produce the primers used in the ATF tests at ARDEC and the supplemental tests at BHA are assumed to be about the same as the NSWC/IHDIV projections. This is because the same batch manufacturing process was used at both organizations, and labor rates are essentially the same.

TASK	CASE A (actual)	CASE B (projected)	CASE C (projected)
Initial Preparation (labor)	3hrs@90= $270	3hrs@40= $120	3hrs@130= $390
Slurry Preparation	2hrs@90=$180	2hrs@40=$80	2hrs@130=$260
Wet Loading	1hr@90=$180	1hr@40=$40	1hr@130=$130
Drying and Testing	3hrs@90=$270	3hrs@40= $120	3hrs@130= $390
Pressing, Repressing, and Anvil Insertion	9hrs@90=$810	9hrs@40= $360	9hrs@130= $1170
Final Inspection	3hrs@90=$270	3hrs@40= $120	3hrs@130= $390
OVHD (60%)	$1134	$504	N/A
Materials 3 g Al (nano 80 nm) 17 g Bi_2O_3	 $30 $10	 $30 $10	 $30 $10
Total Cost per 500 Primers	$3064	$1384	$2770
Total Cost per One Primer	$6.13	$2.77	$5.54

Table 28 – Actual and Projected Costs to Produce a Single Batch of 500 MIC Primers

5.2 Cost Analysis

The cost predictions show that MIC primer batch production at NSWC/IHDIV and ARDEC would be about 10% cheaper than at IMP, but still significantly less than current production costs of PVU-1/A primers at NSWC/IHDIV, which were $7.14 per primer in 2005. For batch production outsourced to private industry with a lower labor cost continuous production capability (Table 28, Case B), the costs are projected to drop by about another 50%. The per primer cost for fully automated mixing and loading, which is obviously non-labor intensive, is expected to drop considerably, perhaps to just a few cents, but has not been calculated. Such an undertaking would involve development of production equipment that does not presently exist, and would be extremely capital equipment intensive. Once the capital equipment is in place, the cost to produce a MIC primer in a fully automated production line should be about the same as the present cost of a #41 primer at LCAAP, which is currently around $0.02 per primer.

6. Implementation Issues

6.1 Environmental Checklist

There are no anticipated regulatory issues with aluminum or bismuth, which are the primary constituents of the MIC primer formulation used as the initiating composition for the small caliber percussion primers.

6.2 End User/Original Equipment Manufacturer Issues

The implementation of the MIC primer should be unnoticeable to the end users. This production would be implemented at LCAAP to replace the current primer assembly facilities under a modernization effort or could be contracted out to civilian firms who meet the quality controls and ship the assembled primers to LCAAP. ATK has been reluctant to implement an automated primer assembly program due to the incompatibility of the current lead styphnate based formulation with automated equipment. The current material has a 'doughy' texture and has not interfaced well with automatic dispensing equipment that work with less viscous materials. The current parallel work being done as part of the ESTCP demonstration has developed a promising process where the MIC material is solvated in water. The texture of the material is currently a slurry, which would be more conducive to automated handling equipment. Scale-up of the present batch mode mixing and loading process needs to be completed before serious investigation of an automated process can begin, however.

7. References

7.1 Numbered References

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5. Jan Puszynski, *MIC Water Based Loading Evaluation*, Final Report, Contract N00174-05-M-0141, Innovative Materials and Processes, LLC, Rapid City, SD June 1, 2006

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8. NAVSEA Instruction 8020.5C *Qualification and Final (Type) Qualification Procedures for Navy Explosives (High Explosives, Propellants, Pyrotechnics and Blasting Agents)*, Naval Sea Systems Command, Arlington, VA 05 May 2000

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8. Points of Contact

Point of Contact	Organization Name	Phone/Fax/Email	Role in Project
John Hirlinger	Armament Research Development and Engineering Center-Picatinny Arsenal	973-724-6498 DSN 880-6498 FAX 973-724-5962 john.m.hirlinger@us.army.mil	ARDEC/ Lead Army Application
Madgy Bichay	Naval Surface Warfare Center -Indian Head Division	301-744-2359 FAX 301-744-2578 magdy.bichay@navy.mil	Navy /Lead Navy Application

Appendix A: Cartridges Using PVU-1/A Percussion Primers

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PVU-1/A 1377-01-108-1438

DODIC	NOMENCLATURE	GFMUNIT	DRAWING	EXPLOSIVE CLASS
DF01	CCU-133/A INT	1	851AS110	1.4
DF06	CCU-132/A INT	1	851AS110	1.4
M205	M114 DLY CTG	1	851AS110	1.4
M207	M90 DLY CTG	1	851AS110	1.4
M208	M70 DLY CTG	1	851AS110	1.4
M209	M93 DLY CTG	1	851AS110	1.4
M213	M46 IMP CTG	1	851AS110	1.4
M276	M155 IMP CTG	1	851AS110	1.4
M277	M271 DLY CTG	1	851AS110	1.4
M282	MK 4-2 DLY CTG	1	851AS110	1.4
M284	MK 5-2 DLY CTG	1	851AS110	1.4
M285	MK 6-2 DLY CTG	1	851AS110	1.4
M299	M231 CARTRIDGE	1	851AS110	1.4
M447	M119 RKT MTR	1	851AS110	1.4
M492	MK 18 CUTTER	1	851AS110	1.4
M500	M21 CUTTER	1	851AS110	1.4
M504	M22 CUTTER	1	851AS110	1.4
M548	MK 127 IMP CTG	1	851AS110	1.4
M576	JAU-2/A INT	1	851AS110	1.4
M370	MK16 IGN	5	851AS110	1.4

PVU-1/A **1377-01-108-1438**

DODIC	NOMENCLATURE	GFMUNIT	DRAWING	EXPLOSIVE CLASS
M743	MK80 RKT MTR	1	851AS110	1.4
M758	JAU-8/A INT	1	851AS110	1.4
M763	M113 INITIATOR	1	851AS110	1.4
M769	CCU-4/A DLY CTG	1	851AS110	1.4
M770	MK 136 DLY CTG	1	851AS110	1.4
M771	MK 141 DLY CTG	1	851AS110	1.4
M772	MK 142 DLY CTG	1	851AS110	1.4
M827	M293 IMP CTG	1	851AS110	1.4
M928	MK82 SEPARATOR	1	851AS110	1.4
M929	MK83 YAW THR	1	851AS110	1.4
M932	MK85 YAW THR	1	851AS110	1.4
M941	MK18 CATAPULT	2	851AS110	1.4
MC51	MK90 SEPARATOR	1	851AS110	1.4
MC53	IMPULSE CTG	1	851AS110	1.4
MC77	MK12-1 CATAPULT	2	851AS110	1.4
MD47	CCU-42/A DLY CTG	1	851AS110	1.4
MD72	MK16-1 CATAPULT	5	851AS110	1.4
MD98	SEAT STABILIZER	1	851AS110	1.4
MF01	.5 SEC DLY CTG	1	851AS110	1.4

PVU-1/A **1377-01-108-1438**

DODIC	NOMENCLATURE	GFMUNIT	DRAWING	EXPLOSIVE CLASS
MF03	CCU-47/A DLY CTG	1	851AS110	1.4
MF04	CCU-52/A IMP CTG	1	851AS110	1.4
MF05	CCU-53/A IMP CTG	1	851AS110	1.4
MF21	MK79-1 RKT MTR	2	851AS110	1.4
MF28	CCU-61/A IMP CTG	1	851AS110	1.4
MF30	CCU-49/A IMP CTG	1	851AS110	1.4
MF31	CCU-51/A IMP CTG	1	851AS110	1.4
MF32	CCU-50/A DLY CTG	1	851AS110	1.4
MF33	CCU-54/A DLY CTG	1	851AS110	1.4
MF34	CCU-55/A DLY CTG	1	851AS110	1.4
MF35	CCU-57/A DLY CTG	1	851AS110	1.4
MF36	CCU-58/A DLY CTG	1	851AS110	1.4
MF37	CCU-59/A DLY CTG	1	851AS110	1.4
MF38	CCU-60/A DLY CTG	1	851AS110	1.4
MF56	MK109 RKT MTR	2	851AS110	1.4
MF57	MK84-2 RKT MTR	2	851AS110	1.4
MF66	CCU-69/A CTG	1	851AS110	1.4
MF72	JAU-27 INT	1	851AS110	1.4
MF96	CCU-73/A DLY CTG	1	851AS110	1.4

PVU-1/A **1377-01-108-1438**

DODIC	NOMENCLATURE	GFMUNIT	DRAWING	EXPLOSIVE CLASS
MG59	CCU-69 IMP CTG	1	851AS110	1.4
MG65	CCU-76/B DLY CTG	1	851AS110	1.4
MG67	MK113 RKT MTR	1	851AS110	1.4
MH78	JAU-47/A INT	2	851AS110	1.4
MH79	JAU-48/A INT	1	851AS110	1.4
MH80	JAU-49/A INT	4	851AS110	1.4
MH81	JAU-50/A INT	4	851AS110	1.4
MH88	CCU-89/A DLY CTG	1	851SA110	1.4
MH89	CCU-86/A DLY CTG	1	851AS110	1.4
MH90	CCU-87/A DLY CTG	1	851AS110	1.4
MH91	CCU-88/A DLY CTG	1	851AS110	1.4
MT05	JAU-58/A INT	1	851AS110	1.4
MT28	MK121 UND RKT	1	851AS110	1.4
MT32	SEAT STABILIZER	1	851AS110	1.4
MU11	CUT 4 SEC DELAY	1	851AS110	1.4
MU76	MK82 ROCKET MTR	2	851AS110	1.4
MU86	GAS GENERATOR	2	851AS110	1.4
MW15	DEPLOYMENT KIT	1	851AS110	1.4
MW80	SAFE ARM DEVICE	1	851AS110	1.4

PVU-1/A **1377-01-108-1438**

DODIC	**NOMENCLATURE**	**GFMUNIT**	**DRAWING**	**EXPLOSIVE CLASS**
XW36	MK205-1 CAT CTG	4	851AS110	1.4
XW52	JAU-25/A INT	1	851AS110	1.4
XW54	JAU-23/A	1	851AS110	1.4
XW55	JAU-24/A	1	851AS110	1.4
XW57	CCU-71 IMP CTG	2	851AS110	1.4
XW58	CCU-72 IMP CTG	2	851AS110	1.4
XW70	SAFE ARM DEVICE	1	851AS110	1.4
XW80	MK84-2 VERNIER	1	851AS110	1.4

Appendix B; Data Quality Assurance/Quality Control Plan

B.1 Purpose and Scope

To identify the quality assurance/quality control methodology that will be used in this hardware demonstration.

B.2 Quality Assurance Responsibilities:

The ARDEC QA person will be Rich Douglas. The NAVSEA/IHDIV QA person will be Magdy Bichay.

B.3 Data Quality Parameters

<u>5.56mm</u>

A small amount of primer will be removed by synthesis personnel for an impact sensitivity test. The material will be withdrawn from the synthesized material in a random manner to ensure that it is representative of the entire blended material. The results of this test are go/no go and will be recorded for each batch. A random sample of assembled primers will be selected by the assemblers for a primer sensitivity test prior to loading into the cartridge case. This test will conducted by assembly personnel with the drop height and go/no go results recorded. All firing tests will be conducted by the range personnel from the Armament Test Facility (ATF), an ISO 9001 certified facility. Data collection will be in accordance with the existing certified procedures for the facility and in accordance to the Small Caliber Ammunition Test Procedures as outline by the November 1998 version of this specification. Per the SCATP, reference cartridges will be used to qualify test set-ups and establish range and equipment corrections prior to firing the demonstration hardware. By definition, reference cartridges have known, documented performance values for each value to be measured. An additional sample of production cartridges will be fired at the ambient temperature condition to provide a data base for comparison to a full production lot.

<u>Navy Primers and Cartridges</u>

An LAT lot of 30 primers is chosen at random from each production lot at NAVSEA/IHDIV. The LAT lot is subjected to the Neyer Sensitvity Test in CAD Test facilities to establish that it meets PVU-1/A sensitivity requirements. Random test firings are made during production of cartridges to ensure that all ballistic parameters are in specification, and the final lot for the demonstration will be subjected to LAT testing at CAD Test. All test and demonstration firings are conducted in accordance with the SOPs given in Section 3.2 and LAT specifications given in Section 3.1. Data collection and reporting procedures are also specified in these documents.

B.4 Calibration Procedures, QC Checks and Corrective Action

<u>5.56mm</u>

All calibration of gages and instrumentation is outsourced to licensed regional facilities based upon the required schedule for each particular piece of equipment.

A calibration history as well as employment history is maintained for all equipment requiring calibration. As described above, reference rounds will be fired prior to the initiation of the demonstration to ensure that all gages and instrumentation is properly functioning. Any readings that are outside the tolerance limits for the reference lot are deemed unacceptable and replacement equipment installed and verified with new firings. The current M855 reference lot is LC87F000R011

Navy Primers and Cartridges

All test and data acquisition equipment utilized in NAVSEA/IHDIV CAD Test facilities is maintained and calibrated according to the NAVSEA-OD45845 instruction. These procedures are carried out in the NAVSEA Dahlgren Division calibration laboratory (Code V540) which is certified to NAVAIR 17-352AC-01 and NAVSEA 04-4734.

B.5 Demonstration Procedures

5.56mm

The demonstration will start with the synthesis of the primer materials. After passing the impact sensitivity test, primers will be loaded. If the sample does not initiate upon impact, the entire batch will be disposed of as explosive waste. Once all primers have been assembled, a sample will be pulled and subjected to a primer sensitivity test to determine if they meet the minimum height specified in the specification. Passing of the test will clear the lot for assembly into cartridges. Again, if the sample of primers does not pass the impact sensitivity test the primer lot will be discarded. Acceptable primers will be loaded into cartridges and used in the demonstration, being subjected to what would normally be considered as the lot acceptance testing associated with primer function.

Navy Primers and Cartridges

All demonstration test procedures are specified in the SOPs and specifications referenced in Sections 3.1 and 3.2. For primer sensitivity testing, a Neyer procedure will be used in place of the specified Bruceton.

B.6 Calculation of Data Quality Indicator

5.56mm

Sample sizes have been selected to achieve basic performance reliability values at an acceptable confidence level for this stage of development (50-70% confidence). The primer sensitivity test will utilize the Neyer rundown method to demonstrate the threshold primer initiation point.

Navy Primers and Cartridges

The calculation procedure for determining primer all-fire and no-fire energies from the 50% all-fire height and standard deviation obtained with the Neyer test is documented in Section 4.2. All other parameters (ignition delay, peak pressure, time to peak pressure, etc.) are measured directly and require no calculations other than conversion of raw data(voltages) to the appropriate parameter via calibration constants, whose fidelity is discussed above. Any averaging of the data will be done for information purposes only, and will use standard statistical techniques to obtain mean values and standard deviations.

B.7 Performance and System Audits

5.56mm

No formal performance or system audits will be conducted as the assembly of the test hardware will be a short duration event. Synthesis and assembly personnel will be adhering to existing general safety and operational SOP's while conducting hand assembly procedures.

Navy Primers and Cartridges

No formal performance and system audits will be performed, and there is no contingincy laboratory. All tests will be conducted in NAVSEA/IHDIV Cad Test facilities under the appropriate SOPs.

B.8 Quality Assurance Reports

5.56mm

There will be one Quality Assurance Report that will include the results of the data analysis of the demonstration.

Navy Primers and Cartridges

There will be one Quality Assurance Report that will include the results of the data analysis of the demonstration.

B.9 ISO 14001

5.56mm

Environmental concerns for the demonstration will be included in the basic operation and clean up of the existing ATF range facility. These concerns are the disposition of excess propellant (normally burned at the arsenal approved burning site) and the collection and disposition of lead contaminated soil used in the impact area.

B.10 Data Format

5.56mm

All firing data from the EPVAT is collected and recorded automatically in a computerized data base. Go/no go data will list the test being performed, date of test, batch/lot number and the result of the test, i.e. Go or No Go

Navy Primers and Cartridges

The format for recording all data to be taken in the demonstration is specified in the SOPs. To provide back-up data, all firing data is collected on hand-written sheets and computer simultaneously. Any result that is out of specification is noted immediately, and re-tests are not permitted unless there has been a verifiable failure of the test equipment.

B.11 Data Storage and Archiving Procedures

5.56mm

Firing data collected at the ATF will be automatically stored on a computer hard drive system. Upon completion of the firings, the data collection personnel will email a copy of the data to all affected projected personnel for analysis and storage. Project personnel then analyze the data and archive it. The POC for the data collection and archiving at ARDEC is Mark Leng.

Navy Primers and Cartridges

All firing data is collected both on paper (hand-written and strip charts) and electronically. All electronic data is archived on disk (HDD, floppy, ZIP, etc.) and after data analysis has been completed, the analyses and data will be permanently stored on a CD. The raw data will permanently reside in the CAD Engineering Department (Code 50) at NAVSEA/IHDIV along with the electronic data. The POC at ARDEC is Mr. Magdy Bichay.

Appendix C: Additional Product Testing for non-JTP Applications

C.1 Small Caliber 5.56mm Green MIC Primer ESTCP Project

MIC primers were made to fit into 5.56mm cartridges. These were made in both solvent (cyclohexane) based process during the year 2005 and also by water based process during the year 2006. The 2005 batch were fired on 24th January 2007 in Armament Technology Facility (ATF) in a 100-meter range. They were fired at ambient, hot, and cold conditions. Standard reference rounds were also fired at ambient conditions for side by side comparative purposes. Case mouth pressure, gas port pressure, action time, and muzzle velocity were measured. The results of 20 ambient temperature reference rounds were as follows:

Ref-011

Shot #	Case Mouth (psi)	Port (psi)	Act Time (us)	Vel (f/s)
1	48,886	16,200	810	2,951
2	50,225	16,683	818	2,976
3	48,585	16,095	826	2,980
4	47,605	17,158	884	2,970
5	48,131	16,477	844	2,961
6	48,069	16,498	872	2,977
7	47,646	16,632	930	2,977
8	47,667	17,044	860	2,971
9	48,657	17,096	870	2,981
10	48,637	16,529	880	2,980
11	49,586	16,560	836	2,999
12	47,574	17,199	884	2,971
13	47,605	16,539	818	2,978
14	49,503	16,570	864	2,998
15	46,563	17,179	886	2,948
16	48,626	17,034	848	2,983
17	47,079	16,756	866	2,959
18	47,677	16,673	872	2,964
19	49,245	16,621	832	2,994
20	49,142	16,467	826	2,996
Avg	**48,335**	**16,701**	**856**	**2,976**
Max	**50,225**	**17,199**	**930**	**2,999**
Min	**46,563**	**16,095**	**810**	**2,948**
Max. Ext	**3,662**	**1,104**	**120**	**51**
Std Dev	**931**	**320**	**30**	**15**
Assess Value (Avg)	**51,157**	**17,292**		**2,956**
Corr. Factor	**2,822**	**592**		**(20)**

The results of 50 ambient temperature conditioned rounds from 2005 batch with green MIC primer were as follows:

005 Ambient

1	48,028	17,137	1,180	2,975
2	47,698	17,282	1,200	2,951
3	50,071	17,127	1,242	2,997
4	47,089	17,705	1,218	2,951
5	48,626	17,643	1,248	2,955
6	50,576	18,087	1,258	2,989
7	49,771	17,663	1,216	2,978
8	48,110	17,127	1,226	2,953
9	48,224	17,271	1,304	2,953
10	48,626	17,065	1,204	2,969
11	49,070	17,096	1,214	2,989
12	49,761	17,220	1,310	2,989
13	50,071	18,128	1,238	2,996
14	49,648	17,591	1,182	2,981
15	48,275	17,024	1,246	2,951
16	46,676	17,230	1,232	2,936
17	49,173	17,024	1,242	2,984
18	49,317	17,024	1,238	2,966
19	50,298	16,477	1,274	2,984
20	49,710	17,117	1,256	2,991
21	49,173	17,179	1,218	2,972
22	49,637	17,540	1,222	2,986
23	48,121	17,158	1,188	2,960
24	49,627	16,725	1,178	2,984
25	46,687	17,137	1,234	2,920
26	49,617	17,746	1,172	2,994
27	49,266	16,952	1,248	2,976
28	48,275	17,498	1,244	2,958
29	48,461	17,179	1,186	2,972
30	49,256	17,313	1,238	2,991
31	48,678	17,612	1,202	2,967
32	49,679	17,591	1,246	2,977
33	49,090	17,065	1,240	2,978
34	49,245	17,086	1,256	2,976
35	50,029	17,591	1,214	2,981
36	48,709	16,962	1,248	2,969
37	49,287	17,158	1,264	2,986
38	49,245	17,674	1,192	2,982
39	47,698	17,210	1,206	2,949
40	49,090	17,086	1,168	2,986
41	49,204	17,591	1,358	2,967
42	49,699	17,694	1,220	2,976
43	49,060	17,581	1,234	2,986
44	48,152	17,653	1,236	2,956
45	49,637	17,024	1,172	2,984
46	48,038	17,106	1,232	2,949
47	48,244	17,168	1,274	2,952
48	48,152	17,013	1,178	2,954

49	49,101	17,127	1,174	2,964
50	48,657	17,044	1,272	2,947
Avg	48,913	17,290	1,229	2,971
Max	50,576	18,128	1,358	2,997
Min	46,676	16,477	1,168	2,920
Max. Extreme	3,900	1,651	190	77
Std Dev	882	326	39	17
Corrected Value:	51,734	17,882		2,951

Excellent agreement between standard reference rounds and green MIC primer rounds is obtained in case mouth pressure, gas port pressure and muzzle velocity. However, action times for green MIC primer rounds are larger than standard reference rounds. The difference is significant and can't be avoided due to the nature of initiation and chemical combustion of chosen energetic materials instead of utilizing unacceptable primary explosives as in standard reference rounds. The action times are still within specifications of existing standard rounds.

The results of 2005 batch, 20 hot green MIC primer rounds, are given below:

005 Hot				
1	56,395	17,168	864	3,082
2	50,215	17,581	1,150	3,014
3	49,060	17,065	1,260	2,993
4	48,667	18,107	1,226	2,967
5	50,256	17,044	1,182	3,005
6	53,321	17,529	1,164	3,078
7	49,235	17,106	1,122	3,021
8	51,381	17,715	1,154	3,025
9	49,926	17,663	1,168	2,999
10	49,761	17,705	1,194	3,005
11	51,319	17,075	1,174	3,029
12	51,845	17,746	1,126	3,046
13	51,402	17,106	1,162	3,044
14	50,236	17,148	1,096	3,029
15	49,235	17,715	1,144	2,994
16	48,791	17,199	1,148	3,012
17	51,247	17,705	1,204	3,026
18	49,802	17,168	1,232	3,001
19	49,751	17,168	1,158	3,011
20	50,236	17,065	1,132	3,016
Avg	**50,604**	**17,389**	**1,153**	**3,020**
Max	**56,395**	**18,107**	**1,260**	**3,082**
Min	**48,667**	**17,044**	**864**	**2,967**
Max. Extreme	**7,728**	**1,063**	**396**	**115**
Std Dev	**1,790**	**326**	**79**	**27**
Corrected Value:	**53,426**	**17,980**		**3,000**

As expected, the pressures and muzzle velocity for hot rounds are higher than ambient rounds. The action time for hot rounds is lower and better than ambient rounds as expected.

The results of 2005 batch, 20 cold green MIC primer, rounds are as follows:

005 Cold				
1	42,415	17,013	1,418	2,855
2	43,065	16,580	1,484	2,843
3	44,654	17,633	1,216	2,891
4	47,739	16,560	914	2,936
5	41,373	16,673	1,416	2,840
6	42,570	16,652	1,284	2,870
7	42,023	16,714	1,316	2,845
8	42,085	17,199	1,448	2,853
9	43,168	16,673	1,260	2,880
10	42,467	17,220	1,476	2,823
11	40,960	17,127	1,450	2,822
12	43,560	17,220	1,426	2,872
13	42,498	17,210	1,406	2,831
14	44,561	16,539	1,446	2,905
15	44,148	17,055	1,298	2,881
16	42,529	16,611	1,312	2,854
17	43,684	16,652	1,494	2,865
18	43,643	17,055	1,378	2,863
19	41,456	16,539	1,496	2,828
20	39,970	16,704	1,332	2,804
Avg	**42,928**	**16,881**	**1,364**	**2,858**
Max	**47,739**	**17,633**	**1,496**	**2,936**
Min	**39,970**	**16,539**	**914**	**2,804**
Max. Extreme	**7,769**	**1,094**	**582**	**132**
Std Dev	**1,647**	**316**	**135**	**31**
Corrected Value:	**45,750**	**17,473**		**2,838**

Again, as expected, the pressures and muzzle velocity of cold rounds are lower than ambient rounds for 2005 solvent based process batch. The action times for cold rounds are longer than ambient rounds. They are all within specifications. Three more standard reference rounds were fired to verify the set-up and integrity of data:

Ref-011				
1	48,812	16,725	836	3,002
2	48,781	17,086	838	2,993
3	48,255	16,983	854	2,974

The standard reference rounds were made with the water based process with the following composition:

32% Barium Nitrate
37% Lead Styphnate
15% Antimony Sulfide
7% Atomized aluminum
5% PETN
4% Tetracene
2% Gum Arabic

It is the intent of this ESTCP program to make green MIC primers as close to the existing manufacturing process of standard primers as possible so that one may be able to adopt it without extensive tooling and set-up and/or compatible with an improved, higher quality process. The water based process lends itself to possibly continuous flow mixing and controlled dispersing by the use of much higher quality devices than the current process. Towards this goal, the batch of 2006 green MIC primers were made with water based process. These were tested on 25th January at ATF. Same sequence and test procedures were followed. The results of 20 reference rounds were given below:

Ref-011

Shot #	Case Mouth (psi)	Port (psi)	Act Time (us)	Vel (f/s)
1	48,853	17,168	884	2,956
2	48,884	16,487	856	2,984
3	49,937	17,158	838	3,008
4	48,936	17,550	868	2,967
5	49,245	17,240	852	2,978
6	49,245	17,158	840	2,986
7	48,802	17,096	858	2,980
8	48,884	17,571	858	2,964
9	48,967	17,705	852	2,969
10	48,265	17,550	850	2,974
11	46,790	17,034	854	2,957
12	47,120	17,075	872	2,947
13	48,368	17,127	886	2,970
14	48,306	17,529	860	2,962
15	47,842	18,107	878	2,972
16	48,224	17,571	832	2,949
17	47,161	17,044	896	2,942
18	47,729	17,447	846	2,939
19	48,750	17,137	842	2,966
20	48,667	17,591	678	2,987
Avg	48,449	17,317	850	2,968
Max	49,937	18,107	896	3,008

Min	46,790	16,487	678	2,939
Max. Extreme	3,147	1,620	218	69
Std Dev	794	344	44	17
Assess Value (Avg)	51,157	17,292		2,956
Corr. Factor	2,708	(25)		(12)

The average results are same as what was obtained before. The results of 50 water based process ambient green MIC primer rounds are as follows:

006 Ambient

Shot #	Case Mouth (psi)	Port (psi)	Act Time (us)	Vel (f/s)
1	51,783	17,148	1,228	3,039
2	51,567	18,117	1,062	3,026
3	51,237	17,767	1,114	2,988
4	53,310	18,148	1,046	3,031
5	54,043	17,663	1,022	3,040
6	50,844	17,622	1,054	3,008
7	50,917	17,498	1,084	3,002
8	50,875	17,694	1,058	2,982
9	51,371	17,602	1,052	3,000
10	52,371	17,148	1,114	3,014
11	49,854	17,622	1,138	2,960
12	51,360	17,591	1,070	3,008
13	52,444	17,158	1,088	3,007
14	49,287	17,633	1,078	2,969
15	50,906	17,148	1,024	3,004
16	52,464	17,034	1,072	3,020
17	50,793	17,509	1,098	3,001
18	52,289	17,622	1,030	3,027
19	53,960	17,581	1,028	3,037
20	51,371	17,633	1,110	3,004
21	49,297	17,653	1,088	2,979
22	49,937	17,602	1,070	2,986
23	51,309	17,591	1,040	3,014
24	51,309	17,509	1,124	3,006
25	53,878	17,509	1,036	3,071
26	51,360	17,633	1,068	2,975
27	51,329	17,591	1,032	3,004
28	52,361	17,571	1,052	3,023
29	55,941	17,106	1,004	3,072
30	51,876	17,137	1,072	3,007
31	51,845	17,591	1,012	3,008
32	52,371	17,633	1,058	3,019
33	54,301	17,127	1,068	3,053

34	52,702	17,591	1,038	3,010
35	50,886	17,488	1,104	2,996
36	54,930	17,560	1,090	3,036
37	49,730	17,137	1,064	2,985
38	51,298	18,190	1,028	3,005
39	51,237	17,581	1,050	3,002
40	50,813	17,519	1,098	2,978
41	49,668	17,117	1,116	2,971
42	53,960	18,066	1,100	3,050
43	51,825	17,086	1,052	3,044
44	52,320	17,086	1,006	3,033
45	51,329	18,066	1,082	3,012
46	52,134	17,725	1,270	3,008
47	53,403	17,519	1,102	3,025
48	54,848	17,117	992	3,077
49	51,825	17,158	1,030	3,018
50	49,307	18,169	1,068	2,985
Avg	51,848	17,527	1,072	3,012
Max	55,941	18,190	1,270	3,077
Min	49,287	17,034	992	2,960
Max. Extreme	6,654	1,156	278	117
Std Dev	1,518	311	50	26
Corrected Value:	54,556	17,502		3,001

The trends of water based process remain same as solvent based process. The water based process closed the gap (difference in results) significantly when compared to standard reference rounds. The action times of water based process rounds are much better than solvent based process rounds. However, still significant differences exist between standard reference rounds and water based process green MIC primer rounds due to its nature of decomposition, not like an explosive. In general, the water based process primers attributed to better performance than solvent based process primers. This is hard to say firmly because there is about one year time elapsed between production of those two batches and aging in a semi-controlled atmosphere and without any sealing may be a factor too.

Next, the 20 water based process rounds at hot conditions were fired. The results follow:

006 Hot

Shot #	Case Mouth (psi)	Port (psi)	Act Time (us)	Vel (f/s)
1	57,210	17,075	1,090	3,107
2	54,002	17,467	1,106	3,052
3	57,334	16,993	1,032	3,103
4	53,052	17,571	1,110	3,047
5	54,187	17,571	1,084	3,053
6	58,139	17,643	1,100	3,130

7	54,652	17,013	1,072	3,092
8	53,929	17,013	1,068	3,074
9	55,394	17,581	1,116	3,033
10	55,663	17,581	1,086	3,073
11	51,371	16,910	1,062	3,028
12	56,457	16,921	1,080	3,102
13	54,063	17,612	1,150	3,064
14	54,569	17,663	1,006	3,078
15	54,569	17,478	1,038	3,076
16	57,221	17,571	984	3,114
17	53,723	17,086	1,054	3,053
18	54,652	17,612	1,054	3,084
19	53,486	18,190	1,088	3,034
20	54,476	17,550	1,142	3,065
Avg	54,907	17,405	1,076	3,073
Max	58,139	18,190	1,150	3,130
Min	51,371	16,910	984	3,028
Max. Extreme	6,768	1,280	166	102
Std Dev	1,672	338	41	29
Corrected Value:	57,616	17,380		3,061

There is no strange behavior. The trends remain the same. The comments made with reference to above atmospheric conditioned rounds are applicable.

To conclude the PVAT test, the last 20 water based process rounds were fired at cold conditions. The results are given below:

006 Cold

Shot #	Case Mouth (psi)	Port (psi)	Act Time (us)	Vel (f/s)
1	42,219	17,096	1,246	2,794
2	45,211	16,993	1,130	2,883
3	46,790	17,148	1,136	2,897
4	48,750	17,055	1,158	2,945
5	44,179	17,013	1,186	2,867
6	44,210	16,890	1,146	2,878
7	44,798	17,003	1,204	2,865
8	44,076	17,550	1,188	2,866
9	45,077	17,663	1,192	2,878
10	45,696	17,075	1,202	2,900
11	44,148	17,725	1,208	2,897
12	48,389	17,086	1,334	2,945

13	48,152	17,581	1,074	2,934
14	46,635	17,612	1,138	2,922
15	44,138	17,044	1,482	2,859
16	44,190	17,179	1,340	2,845
17	43,653	17,075	1,212	2,961
18	46,325	16,993	1,242	2,888
19	47,233	17,550	1,096	2,932
20	46,109	17,106	1,154	2,909
Avg	45,499	17,222	1,203	2,893
Max	48,750	17,725	1,482	2,961
Min	42,219	16,890	1,074	2,794
Max. Extreme	6,531	835	408	167
Std Dev	1,759	272	94	40
Corrected Value:	48,207	17,197		2,881

The trends are same as above with reference to ambient and hot conditions. There is no reason to repeat it. Only one round was misfired. Good firing pin indentation can be seen. The primer was pulled out of the cartridge case and checked for any signs of blank primer cup. There is little coating of primer mix in the cup. Most likely, the primer mix might have fallen into the propellant bed or lost during transportation or LAP operations.

Three more standard reference rounds were fired to check out the set-up and integrity of data. The results are as follows:

1	49,256	17,633	884	2,957
2	48,657	17,106	876	2,963
3	50,875	17,127	868	3,014

The function and casualty (F&C) tests were carried out on solvent based process 2005 batch rounds on 23 Jan 2007. M16A2 rifle was used for this purpose. 20 single shots and 30 in burst mode were fired from 2005 and also 2006 batches. All single shots went through fine. Only one misfire was noticed in burst fire of 2006 lot. This misfire is in addition to another misfire in cold test of 2006 lot. Complete primer indent can be seen after attempt. The most likely cause is either primer mix fell out or availability of not enough primer mixture in that particular primer. The existing manufacturing industry uses a paper disc to hold the primer mix in place. Paper discs weren't used in the fabrication of any of the green MIC primers. The cyclic rate of burst fire was established by firing additional rounds on 25 Jan 2007. A total of 10 rounds were fired in a 3-round burst from standard reference lot and yielded the firing rates of 815, 823, and 825 respectively. Another 19 rounds were fired in a 3-round burst fire from 2005 lot and gave the following firing rates: 798, 773, 776, 791, and 796. Also 17 rounds were fired in a 3-round burst from 2006 batch and yielded the following firing rates: 770, 762, 780, 766, and 768. The solvent based process rounds gave cyclic rates slightly higher than the water based process rounds. Both green MIC primer rounds yielded slightly lower cyclic rates than standard reference rounds. No misfires were evident from either lot. Dispersion test also revealed good results similar to standard reference, M855, rounds.

The water based process gave excellent results. One may be able to adopt it. The limited sensitivity test was performed on both 2005 and 2006 lots in order to make sure that they function as intended before all-up rounds were made. The sensitivity of primers varies from testing machine to machine. It isn't easy to establish a precise sensitivity with the primer testing device in Pyrotechnics Lab. The results vary based on primer strike. The sensitivity of green MIC primers of both solvent based and water based process is always lower than the standard lead based primers.

C.2. Supplemental Ballistic Tests Of 5.56 Caliber Ammunition With MIC Primer

Action time evaluation for various primers in 5.56 mm cartridges with standard propellant

Typical record of a ballistic test carried out in BHA consists of four transients, corresponding to four signals: a trigger, mouth case pressure, port pressure and the screen signal. The transient signals are shown in Figure I-1. The trigger marks time when a fire pin hit the primer (start of the action), while the screen signal indicates time when bullet move above screen detectors placed 13.333 ft from the end of the barrel. These two signals set time differential used later to evaluate action time.

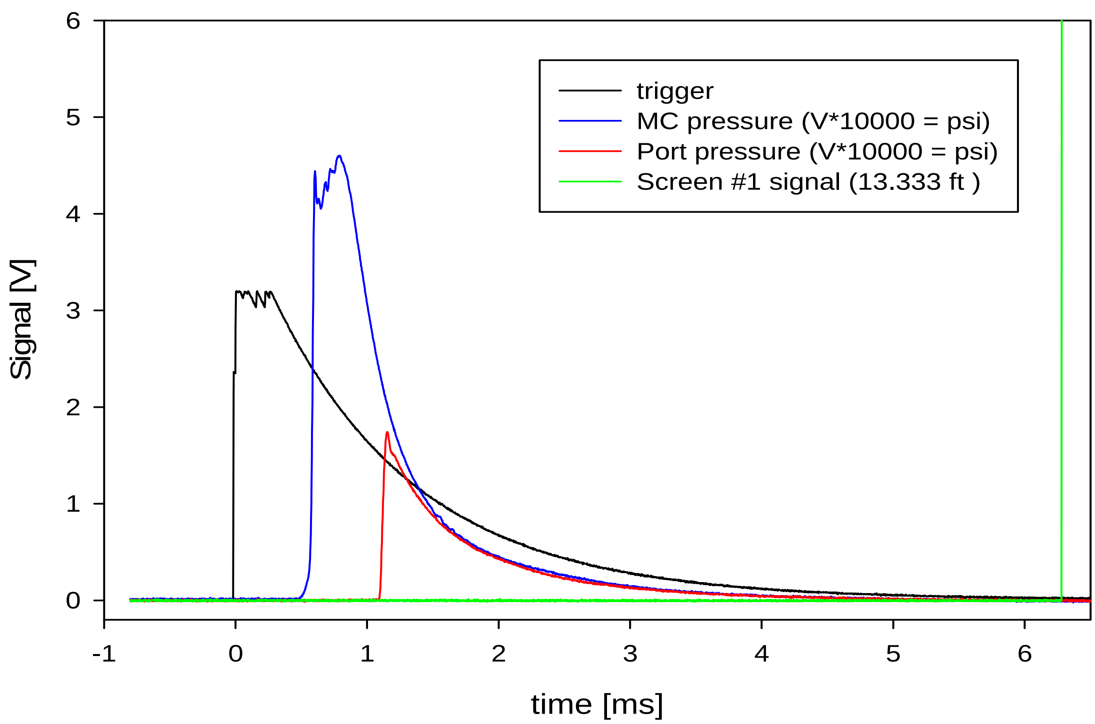

Figure C.2-1. Example of the ballistic test record. Primer # A2. Time differential is measured between onset of the Screen #1 signal and the trigger.

Action time was calculated from time differential using formula: action time = time differential – 13333/velocity + 0.068, where constant 0.068 [ms] stands for the measured time offset between trigger signal and the actual time when fire pin hit the primer. This method of calculation overvalues the action time. Another formula for calculating action time is based on definition that action time is a time from primer strike to first appearance of pressure in the port. Accordingly, a constant 0.068 ms is added to time differential (port – trigger) in order to correct for trigger time delay in the BHA testing device. Tables list results of both calculations; they are marked with * and ** for the first and the second method, respectively.

The results collected for various rounds prepared using Al-Bi_2O_3 MIC primers, modified primers, standard primer #41, modified amount of propellant and fast burning propellant are shown in Tables C.2-1 through C.2-7. Corresponding copies of the ballistic test records are attached at the end.

Table C.2-1. MIC primer, water based loading IMP, ARDEC primer hardware.

Primer #	time differential [ms]	velocity [ft/s]	action time [ms]*	action time [ms]**
A1	6.1760	2692.0000	1.2912	1.0820
A2	6.2980	2684.0000	1.3984	1.1790
A3	6.1760	2686.0000	1.2801	1.0800
A4	6.1760	2697.0000	1.3004	1.1060
A5	6.2720	2688.0000	1.3798	1.1740
A6	6.1660	2700.0000	1.2959	1.0940
A7	6.1580	2702.0000	1.2915	1.0820
A8	6.2280	2673.0000	1.3080	1.1060
A9	6.1060	2713.0000	1.2595	1.0600
A10	6.1220	2705.0000	1.2610	1.0580
	Average	2694.0000	1.3066	1.092
	std	11.7189	0.0464	0.042

Table C.2-2. #41 primer (Winchester), reference.

Primer #	time differential [ms]	velocity [ft/s]	action time [ms]*	action time [ms]**
W1	5.8160	2774.0000	1.0776	0.8860
W2	5.8160	2782.0000	1.0914	0.8920
W3	5.8940	2757.0000	1.1259	0.9320
W4	5.8420	2784.0000	1.1208	0.9280
W5	5.8420	2772.0000	1.1001	0.9000
W6	5.9200	2739.0000	1.1202	0.9300
W7	5.8600	2765.0000	1.1059	0.8940
W8	5.8500	2763.0000	1.0924	0.9040
W9	5.8240	2782.0000	1.0994	0.9040
W10	5.8600	2750.0000	1.0796	0.8910
	Average	2766.8000	1.1013	0.9061
	std	14.9280	0.0169	0.0175

Table C.2-3. MIC primer with 5% PETN, ARDEC primer preparation, LOT 050807-2.

Primer #	time differential [ms]	velocity [ft/s]	action time [ms]*	action time [ms]**
A2-1	6.1920	2695.0000	1.3127	1.1180
A2-2	6.1590	2701.0000	1.2907	1.0840
A2-3	6.2800	2692.0000	1.3952	1.1900
A2-4	6.2980	2676.0000	1.3836	1.1850
A2-5	6.2020	2706.0000	1.3428	1.1400
A2-6	6.2900	2672.0000	1.3681	1.1640
A2-7	6.1400	2697.0000	1.2644	1.0600
A2-8	6.1840	2693.0000	1.3010	1.0970
A2-9	6.2200	2695.0000	1.3407	1.1410
A2-10	6.0960	2718.0000	1.2586	1.0600
	Average	2694.5000	1.3258	1.1239
	std	13.2937	0.0480	0.0480

Table C.2-4. MIC primer with 10% PETN, ARDEC primer preparation, LOT 050807-3.

Primer #	time differential [ms]	velocity [ft/s]	action time [ms]*	action time [ms]**
A3-1	6.0880	2688.0000	1.1958	0.9960
A3-2	6.0620	2707.0000	1.2046	1.0040
A3-3	6.1140	2722.0000	1.2838	1.0880
A3-4	6.0260	2716.0000	1.1849	0.9900
A3-5	6.0960	2701.0000	1.2277	1.0360
A3-6	6.0340	2719.0000	1.1984	1.0060
A3-7	6.0700	2696.0000	1.1925	0.9900
A3-8	6.0260	2721.0000	1.1940	0.9980
A3-9	6.0880	2686.0000	1.1921	0.9880
A3-10	6.0880	2693.0000	1.2050	1.0060
	Average	2704.9000	1.2079	1.0102
	std	13.9718	0.0291	0.0306

Table C.2-5. MIC primer, water based loading IMP, NAVY primer hardware.

Primer #	time differential [ms]	velocity [ft/s]	action time [ms]*	action time [ms]**
N1	6.1080	2718.0000	1.2706	1.0680
N2	6.2100	2675.0000	1.2937	1.0840
N3	6.1580	2700.0000	1.2879	1.0860
N4	6.1840	2677.0000	1.2714	1.0690
N5	6.1580	2693.0000	1.2750	1.0760
N6	6.1580	2695.0000	1.2787	1.0790
N7	6.2020	2682.0000	1.2987	1.0960
N8	6.1660	2693.0000	1.2830	1.0760
N9	6.1760	2689.0000	1.2857	1.0820
N10	6.1400	2698.0000	1.2662	1.0660
	Average	2692.0000	1.2811	1.0782
	std	12.5167	0.0106	0.00927

Non-standard propellant.

Table C.2-6. MIC primer (water based loading, IMP), NAVY primer hardware; added 0.4 grain of propellant in order to increase bullet velocity.

Primer #	time differential [ms]	velocity [ft/s]	action time [ms]*	action time [ms]**
NP1	6.0620	2738.0000	1.2604	1.0580
NP2	6.0520	2744.0000	1.2610	1.0660
NP3	6.0440	2743.0000	1.2513	1.0420
NP4	6.1220	2758.0000	1.3557	1.1700
NP5	5.9900	2757.0000	1.2219	1.0340
	Average	2748.0000	1.2701	1.0740
	std	8.9722	0.0504	0.0551

Table C.2-7. MIC primer (water based loading, IMP), NAVY primer hardware; standard propellant replaced with a fast burning propellant.

Primer #	time differential [ms]	velocity [ft/s]	action time [ms]*	action time [ms]**
F1	6.0700	2751.0000	1.2914	1.2760
F2	6.1240	2717.0000	1.2847	1.0920
F3	6.3580	2761.0000	1.5970	1.0780
F4	6.3140	2751.0000	1.5354	1.4040
F5	6.2020	2753.0000	1.4269	1.3360
F6	6.2540	2738.0000	1.4524	1.2300
	Average	2745.1667	1.4313	1.2360
	std	15.6514	0.1263	0.1308

Below are included test reports from corresponding ballistic tests.

Black Hills Ammunition	14835	6/19/2007	Jack B.
Customer	Reference No.	Test Date	Technician
5.56	HSP EPVAT W1117-1 BHA	870 / 7 RH / 20 in.	709606
Caliber	Barrel ID #	# Rnds / Twist / Length	Receiver #
Sierra	77 / HP WC	Lot "I"	BHA
Bullet Mfg	Weight / Type	Bullet Stock/Lot #	Ammo Source
WCC	WCC06F001-020	MIC0 IMP/ARDEC	
Brass Mfg	Brass Lot Number	Primer Mfg Type	Concent / Comparator

Conformal Transducer			Case Mouth Xdcr.		Port Xdcr.		Sky Screen				Conditioned
			6215SN1405656	1546	6215Sn1392001	1442	13 Ft	17 Ft	73 °F	30 %	°F
Type - SN	Sens.	Offset	Type - SN	Sens.	Type - SN	Sens.	1	2	Temp	RH	Temp

			25.4 -25.4	25.4	2.241 - 2.249	2.245
Ammunition Lot #	Powder Designation	Powder Lot Number	Powder Load	Avg	Overall Length	Avg

Ballistics

Rnd	Cnfrml Pressure	Cnfrml + Offset	Cse Mth Pressure	Port Pressure	Velocity (ft/sec)
1			46,100	17,600	2,692
2			45,900	17,600	2,684
3			45,900	17,500	2,686
4			45,800	17,800	2,697
5			46,000	17,600	2,688
6			46,400	17,700	2,700
7			46,900	17,700	2,702
8			45,400	17,500	2,673
9			47,300	17,900	2,713
10			46,500	17,300	2,705
Average			46,220	17620	2,694
Std. Dev.			563	189	12
Max			47,300	17,900	2,713
Min			45,400	17,300	2,673
ES			1,900	600	40
Correction			984	-1,420	-11
Corrected			**47,204**	**16,200**	**2,683**
Corr Coefficiant < 0.9			0.90		

Parameters - Physical

(Powder/Test Ammo/Ballistics)

POWDER / Lot

25.4 - 25.4	25.4	2.241 - 2.249	2.245
Powder Load	Avg	Overall Length	Avg

DESCRIPTION	ABRV	UNITS	VALUE
Density	BD	g/L	
Density	BD(US)	g/cc	
Volume Mass Density	VMD	grains/cc	
TEST AMMUNITION			
Case volume - total	C-Vol	cc	
Round vol - available	R-Vol	cc	
Charge Mass	CM	g	1.646
Charge Mass	CM	gr	25.40
Charge Volume (powder)	CV	cc	?
Loading Density	LD	%	?
BALLISTICS (Additional Calculations)			
Velocity / Charge	V/C	Fps/grains	105.6
Velocity / Pressure	V/P	Fps/psi	0.0568
Pressure / Velocity	P/V	psi/Fps	17.594

Box Label Infomation

Machine # ____ Date ____

Caliber 5.56 Ammo Lot # ____

Bullet Mfg Sierra Gr. Wt. 77 Type HP WC

Brass Lot # WCC06F001-020 Primer MIC0 IMP/ARDEC

Powder ____ Lot ____

Chg 25.4 - 25.4 OAL 2.241 / 2.249

New ____ Reman ____

Daily ____ Weekly ____ Setup ____

Other Info ____

Comments (Lab Use Only)

MIC0 IMP/ARDEC

Black Hills Ammunition	14637	6/19/2007	Jack B.
Customer	**Reference No.**	**Test Date**	**Technician**
5.56	HSP EPVAT W1117-1 BHA	890 7 RH 20 in.	709606
Caliber	**Barrel ID #**	**# Rnds Twist Length**	**Receiver #**
Sierra	77 HP WC	Lot "I"	BHA
Bullet Mfg	**Weight Type**	**Bullet Stock/Lot #**	**Ammo Source**
WCC	WCC06F001-020	MIC2 IMP/ARDEC	
Brass Mfg	**Brass Lot Number**	**Primer Mfg Type**	**Concent Comparator**

Conformal Transducer			Case Mouth Xdcr.		Port Xdcr.		Sky Screen				Conditioned
			6215SN1405666	1546	6215Sn1392001	1442	13 Ft	17 Ft	73 °F	30 %	°F
Type - SN	Sens.	Offset	Type - SN	Sens.	Type - SN	Sens.	1	2	Temp	RH	Temp

			25.4 -25.5	25.5	2.241 - 2.249	2.245
Ammunition Lot #	**Powder Designation**	**Powder Lot Number**	**Powder Load Avg**	**Overall Length Avg**

Ballistics

Rnd	Cnfrml Pressure	Cnfrml + Offset	Cse Mth Pressure	Port Pressure	Velocity (ft/sec)
1			46,100	17,600	2,695
2			46,300	17,400	2,701
3			46,300	17,500	2,692
4			45,500	17,600	2,676
5			46,100	17,400	2,706
6			45,400	17,300	2,672
7			46,900	17,600	2,697
8			45,900	17,300	2,693
9			45,900	17,500	2,695
10			47,100	17,600	2,718
Average			46,150	17480	2,695
Std. Dev			540	123	13
Max			47,100	17,600	2,718
Min			45,400	17,300	2,672
ES			1,700	300	46
Correction			984	-1,420	-11
Corrected			**47,134**	**16,060**	**2,684**
Corr Coefficiant < 0.9			0.83		

Parameters - Physical

(Powder/Test Ammo/Ballistics)

POWDER / Lot

Powder Load	Avg	Overall Length	Avg
25.4 - 25.5	25.5	2.241 - 2.249	2.245

DESCRIPTION	ABRV	UNITS	VALUE
Density	BD	g/L	
Density	BD(US)	g/cc	
Volume Mass Density	VMD	grains/cc	
TEST AMMUNITION			
Case volume - total	C-Vol	cc	
Round vol - available	R-Vol	cc	
Charge Mass	CM	g	1.646
Charge Mass	CM	gr	25.40
Charge Volume (powder)	CV	cc	?
Loading Density	LD	%	?
BALLISTICS (Additional Calculations)			
Velocity / Charge	V/C	Fps/grains	105.6
Velocity / Pressure	V/P	Fps/psi	0.0569
Pressure / Velocity	P/V	psi/Fps	17.564

Comments (Lab Use Only)

MIC2 IMP/ARDEC

Box Label Infomation

Machine # ______ Date ______

Caliber 5.56 Ammo Lot # ______

Bullet Mfg Sierra Gr. Wt. 77 Type HP WC

Brass Lot # WCC06F001-020 Primer MIC2 IMP/ARDEC

Powder ______ Lot ______

Chg 25.4 -25.5 OAL 2.241 / 2.249

New ______ Reman ______

Daily ______ Weekly ______ Setup ______

Other Info ______

Black Hills Ammunition	14838	6/19/2007	Jack B.
Customer	**Reference No.**	**Test Date**	**Technician**
5.56	HSP EPVAT W1117-1 BHA	900 / 7 RH / 20 in.	709606
Caliber	**Barrel ID #**	**# Rnds / Twist / Length**	**Receiver #**
Sierra	77 HP WC	Lot "I"	BHA
Bullet Mfg	**Weight / Type**	**Bullet Stock/Lot #**	**Ammo Source**
WCC	WCC06F001-020	MIC3 IMP/ARDEC	
Brass Mfg	**Brass Lot Number**	**Primer Mfg Type**	**Concent / Comparator**

Conformal Transducer		Case Mouth Xdcr.		Port Xdcr.		Sky Screen				Conditioned
		6215SN1405666	1546	6215Sn1392001	1442	13 Ft	17 Ft	73 °F	30 %	°F
Type - SN	Sens. Offset	Type - SN	Sens.	Type - SN	Sens.	1	2	Temp	RH	Temp

			25.4 -25.5 / 25.5	2.241-2.249 / 2.245
Ammunition Lot #	**Powder Designation**	**Powder Lot Number**	**Powder Load Avg**	**Overall Length Avg**

Ballistics

Rnd	Cnfrml Pressure	Cnfrml + Offset	Cse Mth Pressure	Port Pressure	Velocity (ft/sec)
1			46,100	17,500	2,688
2			47,000	17,400	2,707
3			47,800	17,400	2,722
4			47,000	17,400	2,716
5			46,600	17,500	2,701
6			46,700	17,100	2,719
7			46,400	16,900	2,696
8			47,600	17,300	2,721
9			46,200	17,400	2,686
10			46,400	17,100	2,693
Average			46,780	17300	2,705
Std. Dev.			571	200	14
Max			47,800	17,500	2,722
Min			46,100	16,900	2,686
ES			1,700	600	36
Correction			984	-1,420	-11
Corrected			**47,764**	**15,880**	**2,694**
Corr Coefficient < 0.9			0.88		

Parameters - Physical

(Powder/Test Ammo/Ballistics)

POWDER / Lot

25.4 - 25.5	25.5	2.241 - 2.249	2.245
Powder Load	Avg	Overall Length	Avg

DESCRIPTION	ABRV	UNITS	VALUE
Density	BD	g/L	
Density	BD(US)	g/cc	
Volume Mass Density	VMD	grains/cc	
TEST AMMUNITION			
Case volume - total	C-Vol	cc	
Round vol - available	R-Vol	cc	
Charge Mass	CM	g	1.646
Charge Mass	CM	gr	25.40
Charge Volume (powder)	CV	cc	?
Loading Density	LD	%	?
BALLISTICS (Additional Calculations)			
Velocity / Charge	V/C	Fps/grains	106.1
Velocity / Pressure	V/P	Fps/psi	0.0564
Pressure / Velocity	P/V	psi/Fps	17.730

Box Label Infomation

Machine # ______ Date ______

Caliber 5.56 Ammo Lot # ______

Bullet Mfg Sierra Gr. Wt. 77 Type HP WC

Brass Lot # WCC06F001-020 Primer MIC3 IMP/ARDEC

Powder ______ Lot ______

Chg 25.4 -25.5 OAL 2.241 / 2.249

New ______ Reman ______

Daily ______ Weekly ______ Setup ______

Other Info ______

Comments (Lab Use Only)

MIC3 IMP/ARDEC

Black Hills Ammunition	14848	6/20/2007	Jack B.
Customer	**Reference No.**	**Test Date**	**Technician**
5.56	HSP EPVAT W1117-1 BHA	923 / 7 RH / 20 in.	709606
Caliber	**Barrel ID #**	**# Rnds / Twist / Length**	**Receiver #**
Sierra	77 HP WC	Lot "I"	BHA
Bullet Mfg	**Weight / Type**	**Bullet Stock/Lot #**	**Ammo Source**
WCC	WCC06F001-020	MIC	
Brass Mfg	**Brass Lot Number**	**Primer Mfg Type**	**Concent / Comparator**

Conformal Transducer		**Case Mouth Xdcr.**		**Port Xdcr.**		**Sky Screen**				**Conditioned**
		6215SN1405666	1546	6215SN1392001	1442	13 Ft	17 Ft	74 °F	45 %	°F
Type - SN	**Sens. Offset**	**Type - SN**	**Sens.**	**Type - SN**	**Sens.**	**1**	**2**	**Temp**	**RH**	**Temp**

			25.5 -25.5	25.5	2.244 - 2.249	2.247
Ammunition Lot #	**Powder Designation**	**Powder Lot Number**	**Powder Load**	**Avg**	**Overall Length**	**Avg**

Ballistics

Rnd	Cnfrml Pressure	Cnfrml + Offset	Cse Mth Pressure	Port Pressure	Velocity (ft/sec)
1				17,300	2,738
2			49,800	17,400	2,751
3			47,800	17,400	2,717
4			50,100	17,200	2,761
5			50,400	17,300	2,751
6			50,600	17,500	2,753
7					
8					
9					
10					
	Average		49,740	17350	2,745
	Std. Dev.		1,126	105	16
	Max		50,600	17,500	2,761
	Min		47,800	17,200	2,717
	ES		2,800	300	44
	Correction		984	-1,420	-11
	Corrected		**50,724**	**15,930**	**2,734**
	Corr Coefficiant < 0.9		0.27		

Parameters - Physical

(Powder/Test Ammo/Ballistics)

DESCRIPTION	ABRV	UNITS	VALUE
POWDER / Lot			
25.5 - 25.5 / 25.5 (Powder Load / Avg)		2.244 - 2.249 / 2.247 (Overall Length / Avg)	
Density	BD	g/L	984
Density	BD(US)	g/cc	0.984
Volume Mass Density	VMD	grains/cc	0.015
TEST AMMUNITION			
Case volume - total	C-Vol	cc	
Round vol - available	R-Vol	cc	
Charge Mass	CM	g	1.652
Charge Mass	CM	gr	25.50
Charge Volume (powder)	CV	cc	1.68
Loading Density	LD	%	?
BALLISTICS (Additional Calculations)			
Velocity / Charge	V/C	Fps/grains	107.2
Velocity / Pressure	V/P	Fps/psi	0.0539
Pressure / Velocity	P/V	psi/Fps	18.552

Comments (Lab Use Only)

MIC Al-Bi2O3 wet loaded

Fast burning double base propellant

Box Label Infomation

Machine # ______ Date ______

Caliber 5.56 Ammo Lot # ______

Bullet Mfg Sierra Gr. Wt. 77 Type HP WC

Brass Lot # WCC06F001-020 Primer MIC

Powder ______ Lot ______

Chg 25.5 -25.5 OAL 2.244 / 2.249

New ______ Reman ______

Daily ____ Weekly ____ Setup ______

Other Info ______

Black Hills Ammunition	14834	6/19/2007	Jack B.
Customer	Reference No.	Test Date	Technician
5.56	HSP EPVAT W1117-1 BHA	860 / 7 RH / 20 in.	709606
Caliber	Barrel ID #	# Rnds / Twist / Length	Receiver #
Sierra	77 / HP WC	Lot "I"	BHA
Bullet Mfg	Weight / Type	Bullet Stock/Lot #	Ammo Source
WCC	WCC06F001-020	MIC0 NAVY	
Brass Mfg	Brass Lot Number	Primer Mfg Type	Concent / Comparator

Conformal Transducer		Case Mouth Xdcr.		Port Xdcr.		Sky Screen				Conditioned
		6215SN1405665	1546	6215Sn1392001	1442	13 Ft	17 Ft	73 °F	30 %	°F
Type - SN	Sens. Offset	Type - SN	Sens.	Type - SN	Sens.	1	2	Temp	RH	Temp

			25.4 -25.4 / 25.4	2.241 - 2.249 / 2.245
Ammunition Lot #	Powder Designation	Powder Lot Number	Powder Load Avg	Overall Length Avg

Ballistics

Rnd	Cnfrml Pressure	Cnfrml + Offset	Cse Mth Pressure	Port Pressure	Velocity (ft/sec)
1			46,800	17,400	2,718
2			45,700	17,700	2,675
3			46,200	17,500	2,700
4			45,500	17,600	2,677
5			45,900	17,600	2,693
6			45,800	17,600	2,695
7			45,500	17,700	2,682
8			47,000	17,600	2,693
9			45,900	17,500	2,689
10			46,200	17,600	2,698
Average			46,050	17580	2,692
Std. Dev.			510	92	13
Max			47,000	17,700	2,718
Min			45,500	17,400	2,675
ES			1,500	300	43
Correction			984	-1,420	-11
Corrected			**47,034**	**16,160**	**2,681**
Corr Coefficiant < 0.9			0.73		

Parameters - Physical

(Powder/Test Ammo/Ballistics)

POWDER / Lot

Powder Load	Avg	Overall Length	Avg
25.4 - 25.4	25.4	2.241 - 2.249	2.245

DESCRIPTION	ABRV	UNITS	VALUE
Density	BD	g/L	
Density	BD(US)	g/cc	
Volume Mass Density	VMD	grains/cc	
TEST AMMUNITION			
Case volume - total	C-Vol	cc	
Round vol - available	R-Vol	cc	
Charge Mass	CM	g	1.646
Charge Mass	CM	gr	25.40
Charge Volume (powder)	CV	cc	?
Loading Density	LD	%	?
BALLISTICS (Additional Calculations)			
Velocity / Charge	V/C	Fps/grains	105.6
Velocity / Pressure	V/P	Fps/psi	0.0570
Pressure / Velocity	P/V	psi/Fps	17.543

Box Label Infomation

Machine # ______ Date ______

Caliber 5.56 Ammo Lot # ______

Bullet Mfg Sierra Gr. Wt. 77 Type HP WC

Brass Lot # WCC06F001-020 Primer MIC0 NAVY

Powder ______ Lot ______

Chg 25.4 -25.4 OAL 2.241 / 2.249

New ______ Reman ______

Daily ____ Weekly ____ Setup ______

Other Info ______

Comments (Lab Use Only)

MIC0 NAVY

Black Hills Ammunition	14839	6/19/2007	Jack B.
Customer	**Reference No.**	**Test Date**	**Technician**
5.56	HSP EPVAT W1117-1 BHA	910 / 7 RH / 20 in.	709606
Caliber	**Barrel ID #**	**# Rnds / Twist / Length**	**Receiver #**
Sierra	77 / HP WC	Lot "I"	BHA
Bullet Mfg	**Weight / Type**	**Bullet Stock/Lot #**	**Ammo Source**
WCC	WCC06F001-020	MIC0 NAVY P	
Brass Mfg	**Brass Lot Number**	**Primer Mfg Type**	**Concent / Comparator**

Conformal Transducer		Case Mouth Xdcr.		Port Xdcr.		Sky Screen				Conditioned
		6215SN1405666	1546	6215Sn1392001	1442	13 Ft	17 Ft	73 °F	30 %	°F
Type - SN	Sens. Offset	Type - SN	Sens.	Type - SN	Sens.	1	2	Temp	RH	Temp

			25.9 - 25.9	25.9	2.241 - 2.249	2.245
Ammunition Lot #	**Powder Designation**	**Powder Lot Number**	**Powder Load**	**Avg**	**Overall Length**	**Avg**

Ballistics

Rnd	Cnfrml Pressure	Cnfrml + Offset	Cse Mth Pressure	Port Pressure	Velocity (ft/sec)
1			48,700	18,100	2,738
2			48,600	17,600	2,744
3			49,200	17,400	2,743
4			50,000	17,400	2,758
5			49,300	17,200	2,757
6					
7					
8					
9					
10					
Average			49,160	17540	2,748
Std. Dev			559	344	9
Max			50,000	18,100	2,758
Min			48,600	17,200	2,738
ES			1,400	900	20
Correction			984	-1,420	-11
Corrected			**50,144**	**16,120**	**2,737**
Corr Coefficiant < 0.9			0.81		

Parameters - Physical

(Powder/Test Ammo/Ballistics)

POWDER / Lot

25.9 - 25.9	25.9	2.241 - 2.249	2.245
Powder Load	Avg	Overall Length	Avg

DESCRIPTION	ABRV	UNITS	VALUE
Density	BD	g/L	
Density	BD(US)	g/cc	
Volume Mass Density	VMD	grains/cc	
TEST AMMUNITION			
Case volume - total	C-Vol	cc	
Round vol - available	R-Vol	cc	
Charge Mass	CM	g	1.678
Charge Mass	CM	gr	25.90
Charge Volume (powder)	CV	cc	?
Loading Density	LD	%	?
BALLISTICS (Additional Calculations)			
Velocity / Charge	V/C	Fps/grains	105.7
Velocity / Pressure	V/P	Fps/psi	0.0546
Pressure / Velocity	P/V	psi/Fps	18.321

Box Label Infomation

Machine # ______ Date ______

Caliber 5.56 Ammo Lot # ______

Bullet Mfg Sierra Gr. Wt. 77 Type HP WC

Brass Lot # WCC06F001-020 Primer MIC0 NAVY P

Powder ______ Lot ______

Chg 25.9 - 25.9 OAL 2.241 / 2.249

New ______ Reman ______

Daily ____ Weekly ____ Setup ______

Other Info ______

Comments (Lab Use Only)

MIC0 NAVY P

Loaded to a higher velocity using an increased powder charge.

Black Hills Ammunition	14636	6/19/2007	Jack B.
Customer	**Reference No.**	**Test Date**	**Technician**
5.56	HSP EPVAT W1117-1 BHA	880 / 7 RH / 20 in.	709606
Caliber	**Barrel ID #**	**# Rnds / Twist / Length**	**Receiver #**
Sierra	77 HP WC	Lot "I"	BHA
Bullet Mfg	**Weight / Type**	**Bullet Stock/Lot #**	**Ammo Source**
WCC	WCC06F001-020	WCC F/P #41	
Brass Mfg	**Brass Lot Number**	**Primer Mfg Type**	**Concent / Comparator**

Conformal Transducer		Case Mouth Xdcr.		Port Xdcr.		Sky Screen				Conditioned
		6215SN1405666	1546	6215Sn1392001	1442	13 Ft	17 Ft	73 °F	30 %	°F
Type - SN	Sens. Offset	Type - SN	Sens.	Type - SN	Sens.	1	2	Temp	RH	Temp

BLH07D120-005			25.4 -25.5	25.5	2.241 -2.249	2.245
Ammunition Lot #	**Powder Designation**	**Powder Lot Number**	**Powder Load**	**Avg**	**Overall Length**	**Avg**

Ballistics

Rnd	Cnfrml Pressure	Cnfrml + Offset	Cse Mth Pressure	Port Pressure	Velocity (ft/sec)
1			50,800	17,200	2,774
2			52,300	17,400	2,782
3			50,400	17,600	2,757
4			50,800	17,300	2,784
5			50,400	17,300	2,772
6			49,400	17,900	2,739
7			49,900	17,300	2,765
8			50,400	17,200	2,763
9			50,600	17,300	2,782
10			50,500	17,600	2,750
Average			50,550	17410	2,767
Std. Dev			746	223	15
Max			52,300	17,900	2,784
Min			49,400	17,200	2,739
ES			2,900	700	45
Correction			984	-1,420	-11
Corrected			**51,534**	**15,990**	**2,756**
Corr Coefficiant < 0.9			0.69		

Parameters - Physical
(Powder/Test Ammo/Ballistics)

DESCRIPTION	ABRV	UNITS	VALUE
POWDER / Lot			
Powder Load 25.4 - 25.5, Avg 25.5; Overall Length 2.241 - 2.249, Avg 2.245			
Density	BD	g/L	984
Density	BD(US)	g/cc	0.984
Volume Mass Density	VMD	grains/cc	0.015
TEST AMMUNITION			
Case volume - total	C-Vol	cc	
Round vol - available	R-Vol	cc	
Charge Mass	CM	g	1.646
Charge Mass	CM	gr	25.40
Charge Volume (powder)	CV	cc	1.67
Loading Density	LD	%	?
BALLISTICS (Additional Calculations)			
Velocity / Charge	V/C	Fps/grains	108.5
Velocity / Pressure	V/P	Fps/psi	0.0535
Pressure / Velocity	P/V	psi/Fps	18.700

Comments (Lab Use Only)

WCC F/P #41

Box Label Infomation

Machine # 18 Date 6/19/2007
Caliber 5.56 Ammo Lot # BLH07D120-005
Bullet Mfg Sierra Gr. Wt. 77 Type HP WC
Brass Lot # WCC06F001-020 Primer WCC F/P #41
Powder Lot
Chg 25.4 - 25.5 OAL 2.241 / 2.249
New Reman
Daily Weekly Setup
Other Info